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Utah Lake-Jordan River Basin Modeling Project. Volume I. Summary Report

Environmental Dynamics, Inc, Los Angeles, Calif

Prepared for

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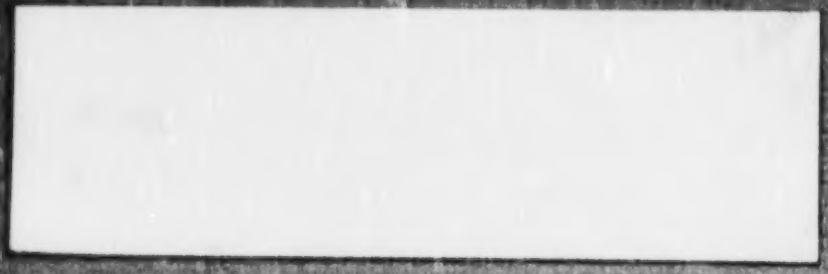

ENVIRONMENTAL DYNAMICS, INC.
CONSULTING ENGINEERS AND SYSTEMS ANALYSTS

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UTAH LAKE-JORDAN RIVER

BASIN MODELING PROJECT

Volume I - Summary Report

Submitted to

Environmental Protection Agency
Office of Water Quality
Washington, D.C.

By

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October 1973

PREFACE

THE UTAH LAKE-JORDAN RIVER BASIN MODELING PROJECT
by Environmental Dynamics, Inc.

U.S. Environmental Protection Agency
Contract #68-01-0775

Presented in three volumes

Volume I - Summary Report

Volume II - Data Report

Volume III - Documentation, Verification, and Sensitivity

(Volume III includes the program listings for EDI's QUAL II and EDI's Deep Reservoir Model II for the entire Utah Lake-Jordan River System)

Volume I - Summary Report

TABLE OF CONTENTS

INTRODUCTION	1
OBJECT	1
SCOPE	2
DESCRIPTION OF MODIFIED CODES	3
BASIC FLOW AND MASS BALANCE FORMULATION	3
QUAL II	4
MODIFIED DEEP RESERVOIR MODEL	8
APPLICATION OF QUAL II	10
SYSTEM LAYOUT	10
DATA AVAILABILITY	18
APPLICATION OF QUAL	22
APPLICATION OF DEEP RESERVOIR MODEL TO DEER CREEK RESERVOIR	35
DATA AVAILABILITY	35
SIMULATION RESULTS	36
CONCLUSIONS	45
MODEL CAPABILITIES	45
RECOMMENDATIONS	46

INTRODUCTION

The waste assimilation capacity of streams and impoundments is the result of complex chemical, physical, biological and hydraulic factors. Description of these factors and the determination of this assimilation capacity for a given time period is a difficult task at best.

Implementation of mathematical modeling systems, with their detailed consideration of numerous elements defining the hydraulic and water quality characters of drainage basins, allows for refined water planning. Evaluating effects of various treatment schemes, predicting river conditions during periods of extreme climatological conditions, or analysis of the cause and effect relationships within systems are facilitated by the use of mathematical models.

OBJECT

Development of water quality simulation models requires an understanding of the external forces contributing to the streams and reservoirs. In addition, the factors affecting the internal composition of the waters must be considered. Detailed consideration of the external as well as internal facets of water quality has resulted in several versatile but complex mathematical water simulation systems. The object of this study was to take two previously developed simulation systems, expand their routing capabilities and apply them to the Utah Lake-Jordan River Basin. The stream

simulation model, QUAL, was developed by the Texas Water Development Board. This model was to be utilized to simulate the rivers and main tributaries of the basin. For simulation of Deer Creek Reservoir, Deep Reservoir Model, developed by Water Resources Engineers, Inc., was chosen.

Both models with original routing capabilities ranging from streamflow and water temperature only to streamflow, water temperature, dissolved oxygen, biochemical oxygen demand and conservative minerals were expanded to route a wide range of water quality indices.

The models were modified in such a manner as to maintain their versatility. Accordingly, the modifications were of a general nature to allow application to basins of diverse drainage configurations and localities.

The modified codes were then adapted and tested on elements of the Utah Lake-Jordan River Drainage Basins for the dual purpose of verifying the routing capabilities of the models and of providing planning models for use by local officials.

SCOPE

This project was conducted under several guidelines:

1) Modifications were not to include major structural changes in the existing computer codes. Modifications were to supplement rather than replace original programs.

2) All programming was to be done in FORTRAN IV (level G) and the programs were to be executed under Release 20.1 and HASP 3.0 on either the IBM 360/65 or IBM 370/155.

3) The resulting models were to be "working models" easily utilized by the user for planning purposes.

4) All models were to be verified by application to components of the Utah Lake-Jordan River Basin, utilizing historic data.

5) Complete documentation of modifications and applications were to be provided. Modifications were to be documented in such a manner as to supplement existing documentation.

DESCRIPTION OF MODIFIED CODES

BASIC FLOW AND MASS BALANCE FORMULATION

A one-dimensional mass balance analysis is used to route constituents in both models. Equation (1) represents the general case:

$$(1) \qquad A\frac{\partial C}{\partial t} = \frac{\partial\left(AD_L\frac{\partial C}{\partial x}\right)}{\partial x} - \frac{\partial(A\bar{u}C)}{\partial x} \pm AS^*$$

where: A = Cross-sectional area (L^2)

C = Constituent concentration (mg/l)

D_L = Longitudinal dispersion coefficient (ft^2/sec)

$\bar{u}$ = Mean velocity of the stream (ft/sec)

t = Some point in time (sec)

x = Direction of flow (ft)

S*= Sources or sinks of nonconservative constituents (mg/l)

The first two terms, advection and dispersion, reflect the hydraulic conditions and related mass transfer phenomena existing in a given system. These terms are independent of biological and chemical reactions, and therefore do not vary with constituents. In fact, as the area (A) is also quality independent, Equation (1) varies from constituent to constituent only in the definition of internal sources and internal sinks. The various internal sources and sinks are represented by accepted first order equations. Table I lists the general forms of these equations which consider such factors as reaeration, constituent decay, and interaction with the benthos or aquatic flora.

There is some variation in the formulations between QUAL II and Modified Deep Reservoir Model, as the new models were named. These variations and particulars of model capabilities are explained in the following sections.

QUAL II

QUAL II is a refined stream simulation system, composed of a set of interrelated quality routing models. The governing equation, described earlier, for the transport of conservative and non-conservative substances, is used without modification by QUAL II:

TABLE I

EQUATIONS DEFINING "SOURCES AND SINKS"

Parameter	Equation	Comments
Carbonaceous BOD	$dL/dt = K_M - K_1 L$	K_M = BOD contribution by benthos L = BOD concentration K_1 = BOD reaction rate
Organic Nitrogen	$\frac{d(N_{ORG})}{dt} = K_B(A_1+A_2) - K_{KJ}(N_{ORG})$	K_B=rate of organic nitrogen production by algae, (1/days) A_1=the chlorophyll a concentration resulting from phytoplankton, (mg/l) A_2=the chlorophyll a concentration resulting from sessile algae, (mg/l) K_{KJ}=organic nitrogen decay rate constant, (1/days) N_{ORG}=organic nitrogen concentration, (mg/l)
Ammonia	$\frac{d(NH_4)}{dt} = K_{KJ}(N_{ORG}) - K_{NH_4}(NH_4)$	K_{NH4}=ammonia decay rate constant, (1/days) NH_4 =ammonia concentration, (mg/l)
Nitrite	$\frac{d(NO_2)}{dt} = K_{NH_4}(NH_4) - K_{NO_2}(NO_2)$	K_{NO2}=nitrite nitrogen decay rate constant, (1/days) NO_2 =nitrite concentration, (mg/l)

TABLE I (cont'd)

EQUATIONS DEFINING "SOURCES AND SINKS"

Parameter	Equation	Comments
Nitrate	$\frac{d(NO_3)}{dt} = K_{NO_2}(NO_2) - K_B(A_1+A_2)$	
Dissolved Oxygen	$\frac{do}{dt} = K_2(O_S-O)+K_A(A_1+A_2)-K_1L$ $-2.29K_{NH_4}(NH_4)-1.14K_{NO_2}(NO_2)$	K_2 = reaeration coefficient, (1/days) O_S = saturation value of oxygen, (mg/l) O = dissolved oxygen concentration, (mg/l)
Phosphorus	$\frac{d(PO_4)}{dt} = -K_{(PO_4)_1}(PO_4)$ $-K_{(PO_4)_2}(A_1+A_2)$	$K_{(PO_4)_1}$ = first order decay rate of phosphorus, (1/days) $K_{(PO_4)_2}$ = rate constant of phosphorus uptake by algae, (1/days) PO_4 = phosphorus concentration, (mg/l)
Coliforms	$\frac{dCOL}{dt} = -K_{COL}(COL)$	K_{COL} = die-off constant of coliforms, (1/days) COL = coliform concentration, (MPN/100 ml)
Conservative Minerals	$\frac{d(CONS)}{dt} = 0$	CONS = conservative constituent concentration (mg/l)

$$(4) \qquad C = \frac{\left(AD_L \frac{\partial C}{\partial x}\right)}{\partial x} - \frac{\partial (A\bar{u}C)}{\partial x} \pm AS^*$$

This equation is a second order, linear, parabolic partial differential equation. For a section of a river of length L, the following initial and boundary conditions apply for Equation (4):

$$C(X,0) = C_o \quad 0 \leq X \leq L \qquad (a)$$

$$C(0,t) = C^*_o \qquad (b)$$

$$\left.\frac{\partial C}{\partial x}\right|_{x=L} = 0 \qquad (c)$$

Boundary condition (c) assumes neglibible dispersion upstream from the headwater source.

Equation (4) with the given initial and boundary condition does not have a closed-form solution. QUAL uses an implicit numerical procedure for the solution of Equation (4) subject to conditions (a), (b) and (c). The length of the river is discretized into a series of computational elements. Complete mixing is assumed in each element. The time domain is similarly discretized.

QUAL II provides both temporal and spacial descriptions of the modeled river segment. A wide range of water quality indices can be considered:

<u>Non-Conservative Constituents</u>

- Streamflow
- Fecal Coliforms

- Water Temperature
- Dissolved Oxygen
- BOD
- Phosphorus
- Total Coliforms
- Organic Nitrogen
- Ammonia
- Nitrite
- Nitrate

Conservative Constituents

- Total Dissolved Solids
- Total Nitrogen

Data requirements for simulation with QUAL II fall into one of three categories:

1) Tributary Data: composed of steady-state flow and constituent concentration values describing conditions in the tributaries, wastewater treatment plant effluents, and industrial discharges

2) Mainstream Data: describing initial conditions existing in mainstream, as well as physical characteristics of the channel

3) Climatological Data: composed of readily available data utilized for thermal modeling

Programming is in FORTRAN IV (level G). QUAL II is presently compatible with IBM 360/65 and IBM 370/155 systems. Core storage requirements are 250 K.

MODIFIED DEEP RESERVOIR MODEL

Modified Deep Reservoir Model (DRM II) simulates the seasonal

evolution of thermal and water quality conditions within reservoirs and impoundments. Using three modules -- 1) water balance, 2) meteorological data assimilation, and 3) simulation, the model develops the hydrologic, thermal, and quality character of impoundments.

In the development of the quality aspects of DRM II Equation (1) is reduced to Equation (5):

(5) $$\frac{dC}{dt} = \pm \; S^*$$

There are no terms included for advection or dispersion because it was assumed that there is no flow along a horizontal axis. The flow through a deeply stratified reservoir generally has a retention time exceeding several months, making the above assumption quite reasonable. Further, it was assumed that constituents exist in separate, isolated layers, meaning that there is no diffusion between the layers. Hence the governing equation simply reduces to a consideration of sources and sinks.

The basic relationships developed earlier to define the term sources and sinks require minor modifications when applied to impoundments. DRM II predicts for any time of the year the concentration of the following constituents at various depths and within outlet flows:

- Water Temperature
- Fecal Coliforms
- Dissolved Oxygen
- Organic Nitrogen*

*Organic nitrogen here is effectively a measure of the ambient algae population.

- BOD
- Phosphorus
- Total Coliforms
- Ammonia
- Nitrate
- Conservative Minerals

Data requirements include:

1) Description of physical character of reservoir
2) Meteorological data for period of simulation
3) Initial conditions existing within reservoir
4) Flow rates and the quality of tributaries during the period of simulation

Deep Reservoir Model programming is in FORTRAN IV (level G and H) and is presently compatible with IBM 360/65 and 370/155 systems. Storage requirements are 250 K.

APPLICATION OF QUAL II

SYSTEM LAYOUT

The flow regimes of Utah Lake-Jordan River basin were segmented into seven smaller subsystems. QUAL systems were determined through consideration of four limiting factors:

1) Each QUAL system is limited to a maximum of 20 reaches
2) QUAL cannot route through large impoundments with accurate results
3) QUAL is unable to route more than one headwater

on a tributary to the mainstream

4) Systems routed by QUAL are limited to five headwaters

System 1 - Currant Creek (Figure 1)

The selected headwater for Currant Creek is the outlet at Mona Reservoir. After the stream enters Goshen Reservoir the remaining stream flow is dispersed into a marsh which drains into Utah Lake. However, since traceable streamflow does not reach Utah Lake, Currant Creek is modeled as an independent system.

System 2 - Upper Provo River (Figure 2)

The headwater of the Provo River System is located by contract at the U.S.G.S. gaging station above Hailstone, Utah. This system extends down the Upper Provo River to Deer Creek Reservoir. The system is terminated here because of QUAL's restrictions in deep impoundments.

System 3 - Spanish Fork (Figure 3)

This system encompasses Soldier Creek, Thistle Creek, Diamond Fork, Sixth Water Creek and Spanish Fork in the modeling flow regime. System 3 ends at the mouth of Spanish Fork, where it joins Utah Lake. System 3 is terminated at this point for two reasons:

1) Including the three headwaters of Spanish Fork

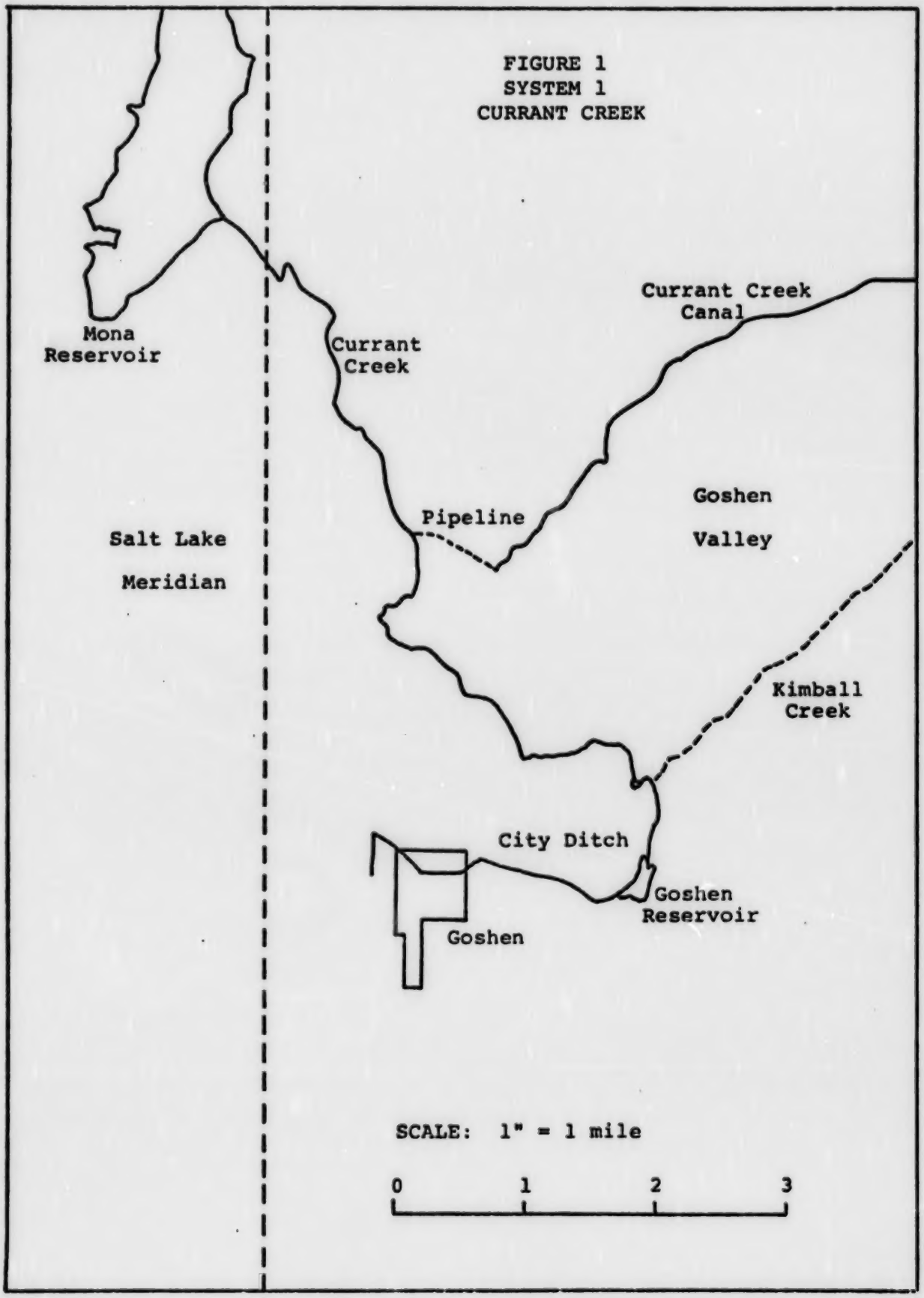


FIGURE 1
SYSTEM 1
CURRANT CREEK
Mona
Reservoir
Currant
Creek
Currant Creek
Canal
Pipeline
Goshen
Valley
Salt Lake
Meridian
Kimball
Creek
City Ditch
Goshen
Reservoir
Goshen
SCALE: 1" = 1 mile
0
1
2
3

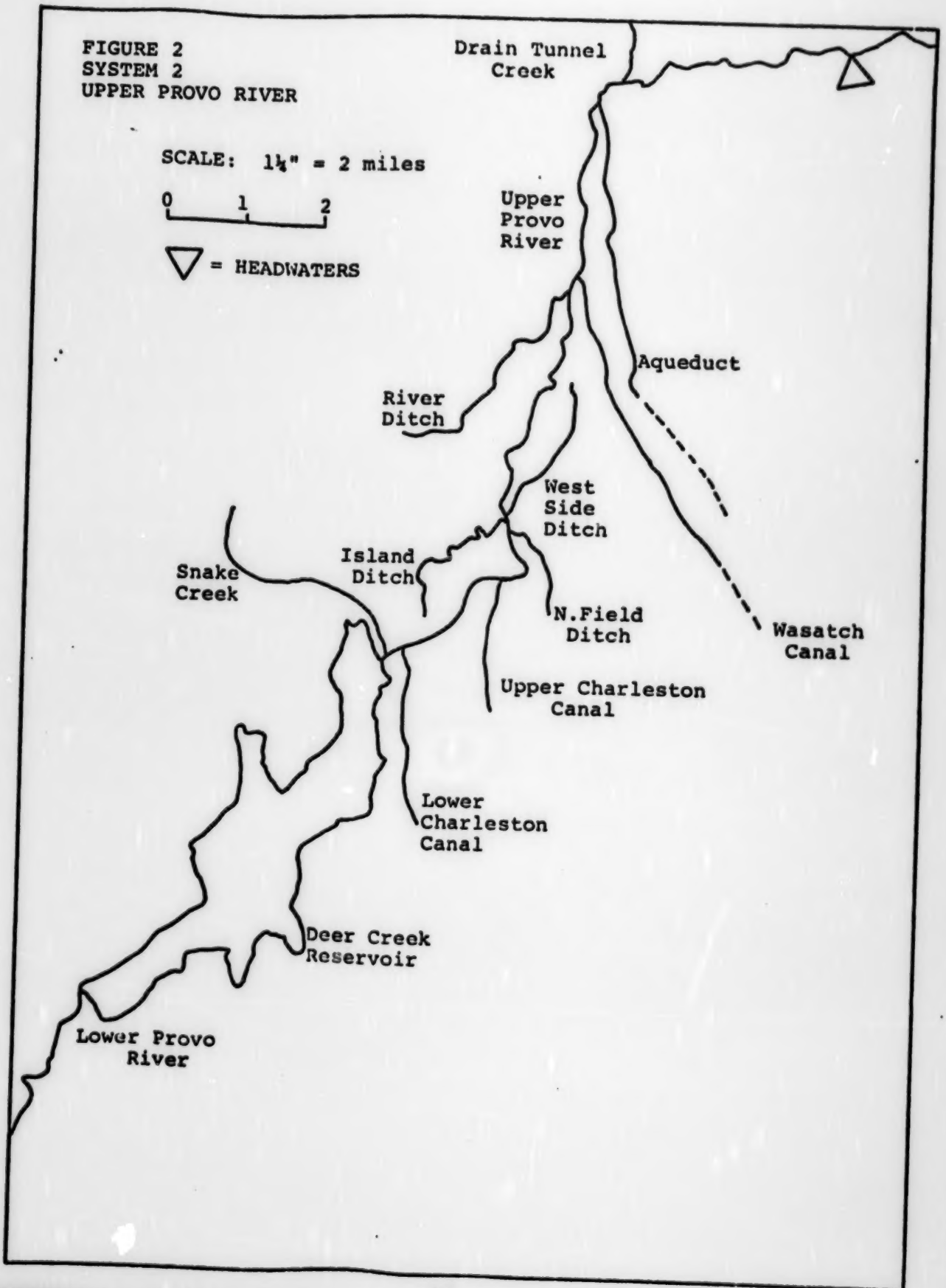


FIGURE 2
SYSTEM 2
UPPER PROVO RIVER
SCALE: 1¼" = 2 miles
0 1 2
= HEADWATERS
Drain Tunnel Creek
Upper Provo River
Aqueduct
River Ditch
West Side Ditch
Island Ditch
Snake Creek
N.Field Ditch
Wasatch Canal
Upper Charleston Canal
Lower Charleston Canal
Deer Creek Reservoir
Lower Provo River

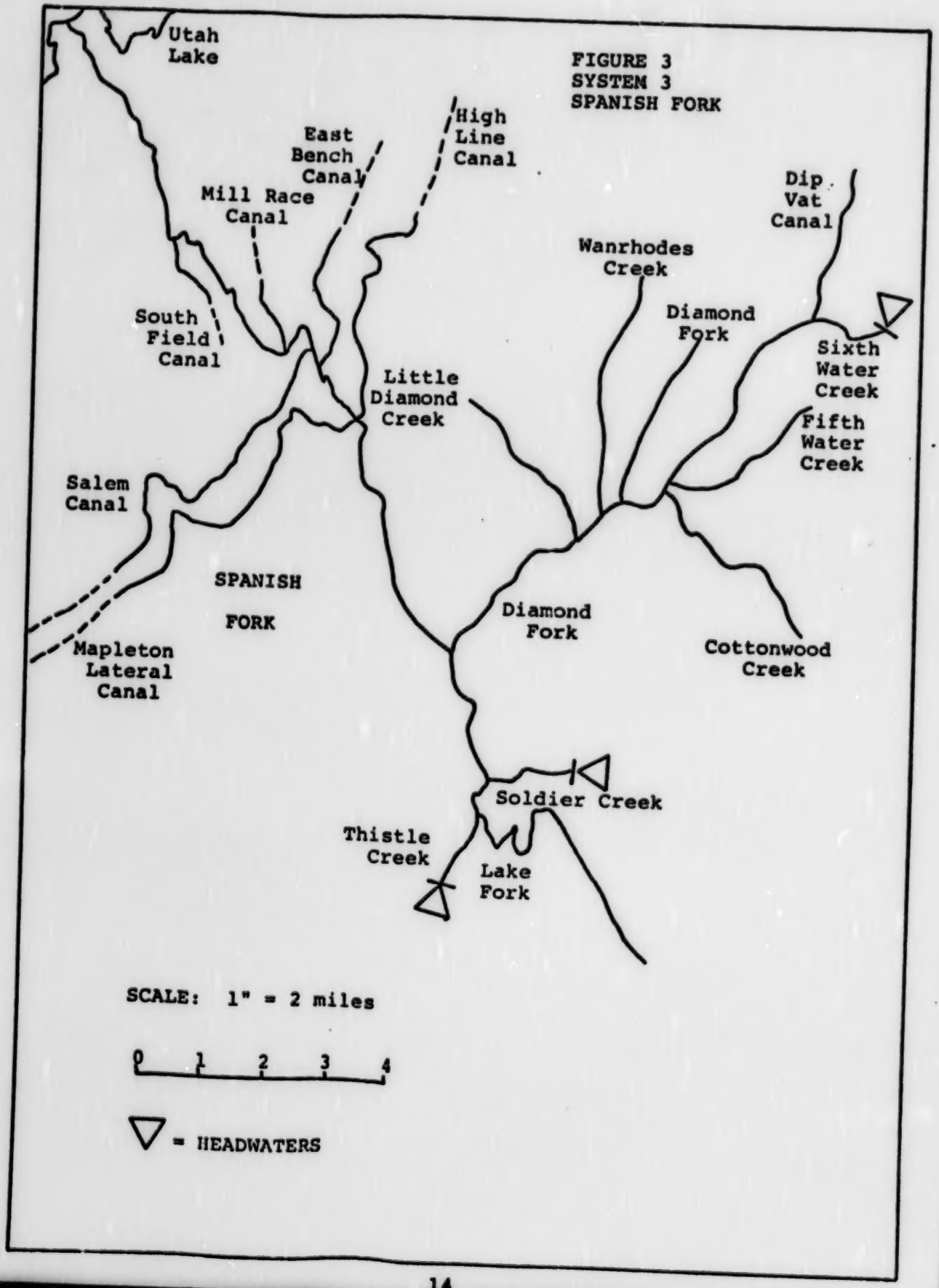


FIGURE 3
SYSTEM 3
SPANISH FORK
Utah Lake
High Line Canal
East Bench Canal
Mill Race Canal
Dip Vat Canal
Wanrhodes Creek
Diamond Fork
South Field Canal
Sixth Water Creek
Little Diamond Creek
Fifth Water Creek
Salem Canal
SPANISH FORK
Diamond Fork
Mapleton Lateral Canal
Cottonwood Creek
Soldier Creek
Thistle Creek
Lake Fork
SCALE: 1" = 2 miles
0 1 2 3 4
= HEADWATERS

routed through Utah Lake seven headwaters would result, thus exceeding QUAL's capabilities

2) Continued routing of all tributaries of Utah Lake in one system would result in trying to model several headwaters on one tributary, e.g. Thistle Creek and Sixth Water Creek upon Soldier Creek

System 4 - Utah Lake (Figure 4)

System 4 entails the modeling of Hobble Creek, Dry Creek, American Fork, Lower Provo River and Utah Lake. Utah Lake is routed as a well-mixed stream segment with Dry Creek, American Fork and Hobble Creek as tributaries routed from contract-designated headwaters. The Lower Provo River begins at the outflow of Deer Creek Reservoir. This system ends at the outlet of Utah Lake. Further routing would require more than the permitted number of reaches.

Jordan River Basin

The Jordan River along with its seven Wasatch Mountain tributaries were divided into 48 reaches calling for three systems.

System 5 - Upper Jordan River (Figure 5)

The Upper Jordan River's headwater is Utah Lake. The river flows over many large diversions and System 5 ends at Jordan River mile 26.

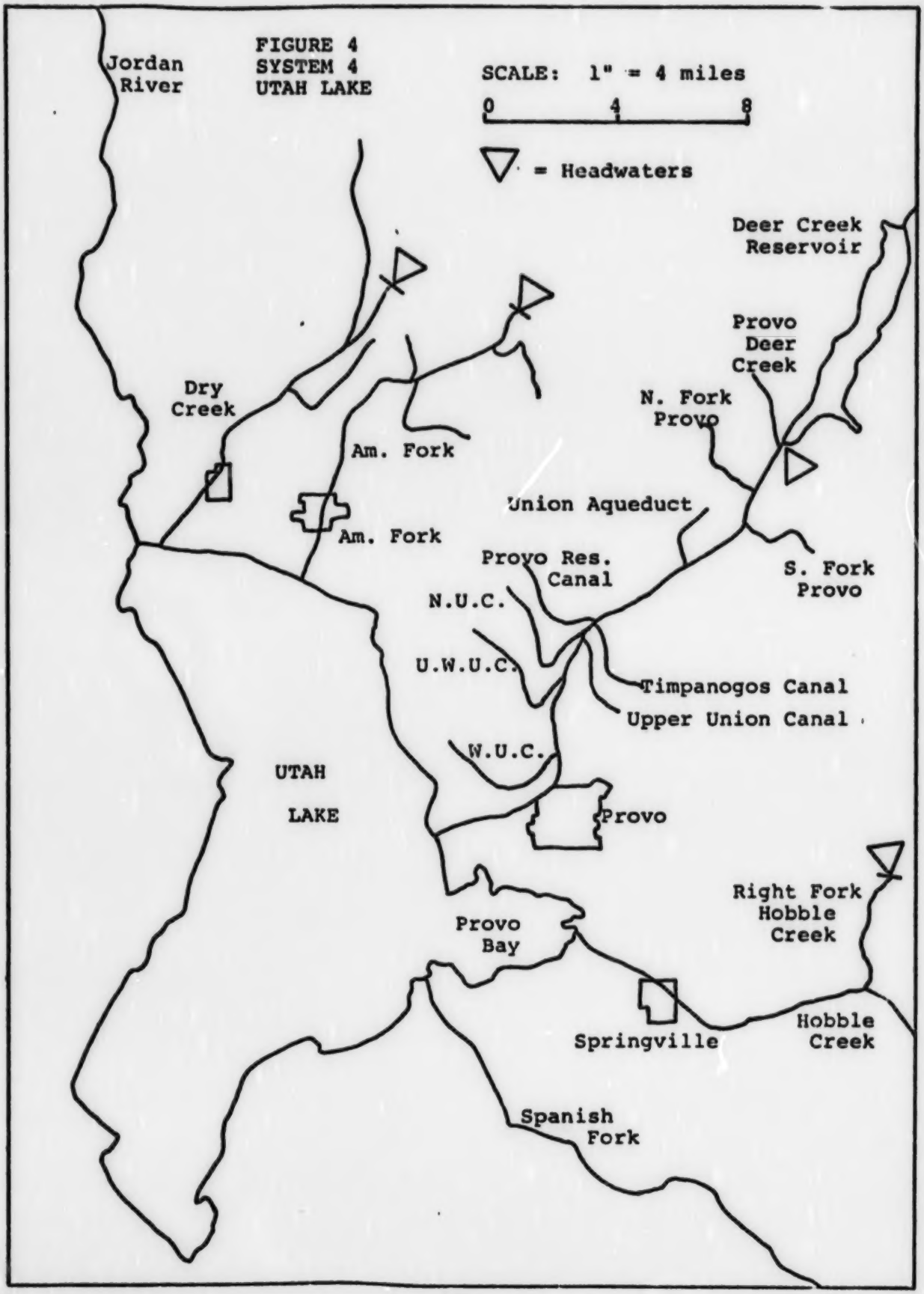
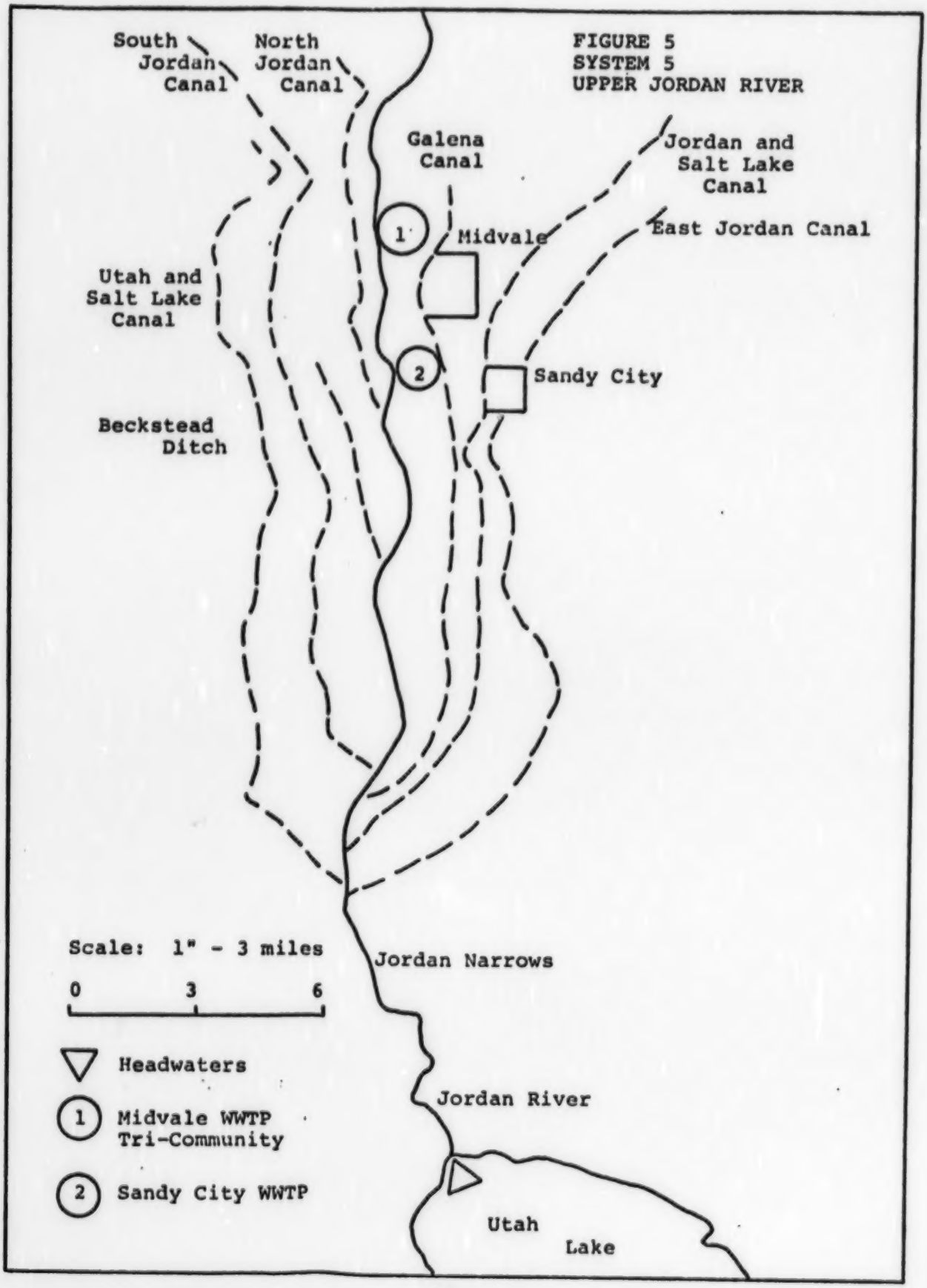


FIGURE 4
SYSTEM 4
UTAH LAKE
SCALE: 1" = 4 miles
0 4 8
= Headwaters
Jordan River
Deer Creek Reservoir
Provo Deer Creek
N. Fork Provo
Dry Creek
Am. Fork
Am. Fork
Union Aqueduct
Provo Res. Canal
S. Fork Provo
N.U.C.
U.W.U.C.
Timpanogos Canal
Upper Union Canal
W.U.C.
UTAH LAKE
Provo
Right Fork Hobble Creek
Provo Bay
Springville
Hobble Creek
Spanish Fork


South Jordan Canal
North Jordan Canal
FIGURE 5
SYSTEM 5
UPPER JORDAN RIVER
Galena Canal
Jordan and Salt Lake Canal
East Jordan Canal
1
Midvale
Utah and Salt Lake Canal
2
Sandy City
Beckstead Ditch
Scale: 1" - 3 miles
0
3
6
Jordan Narrows
Headwaters
Jordan River
1
Midvale WWTP Tri-Community
2
Sandy City WWTP
Utah Lake

System 6 - Central Jordan River (Figure 6)

The selected headwater lies at river mile 26, which is the end of System 5. Little Cottonwood, Big Cottonwood and Mill Creek are tributaries to the Central Jordan and their headwaters were specified by contract. The end of the Central Jordan System is at the diversion dam of the Surplus Canal which diverts more than half of the flow during the verification period. This results in major hydraulic changes in the Central Jordan mainstream. Therefore, this terminal point was selected for System 6.

System 7 - Lower Jordan River - (Figure 7)

This segment of the Jordan River extends to its terminus at the Great Salt Lake. Parleys Creek, City Creek, Emigration Creek and Red Butte Creek are all tributaries along the Lower Jordan designated as headwaters. The selected headwater of System 6 is thirteen miles up Parleys Canyon from Parleys Creek confluence with Emigration Creek. Parleys Creek, Emigration Creek and Red Butte Creek merge in the Salt Lake City storm conduit system before their confluence with the Jordan River.

DATA AVAILABILITY

Flow records on the seven systems are excellent. U.S.G.S. stations provide descriptions of mainstream flow at numerous

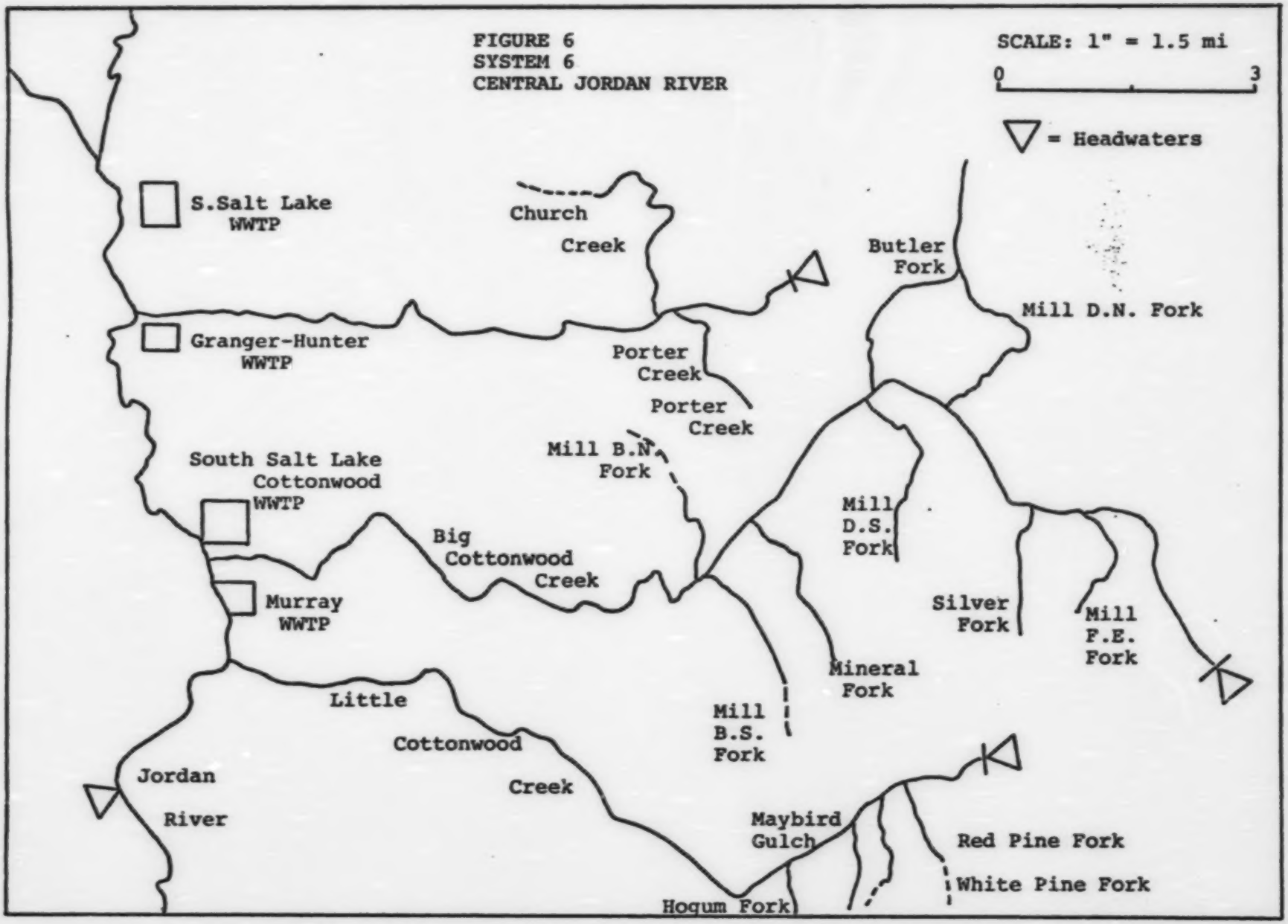


FIGURE 6
SYSTEM 6
CENTRAL JORDAN RIVER
SCALE: 1" = 1.5 mi
0
3
= Headwaters
S.Salt Lake WWTP
Church Creek
Butler Fork
Mill D.N. Fork
Granger-Hunter WWTP
Porter Creek
Porter Creek
Mill B.N. Fork
South Salt Lake Cottonwood WWTP
Mill D.S. Fork
Big Cottonwood Creek
Murray WWTP
Silver Fork
Mill F.E. Fork
Mineral Fork
Little Cottonwood Creek
Mill B.S. Fork
Jordan River
Maybird Gulch
Red Pine Fork
White Pine Fork
Hogum Fork

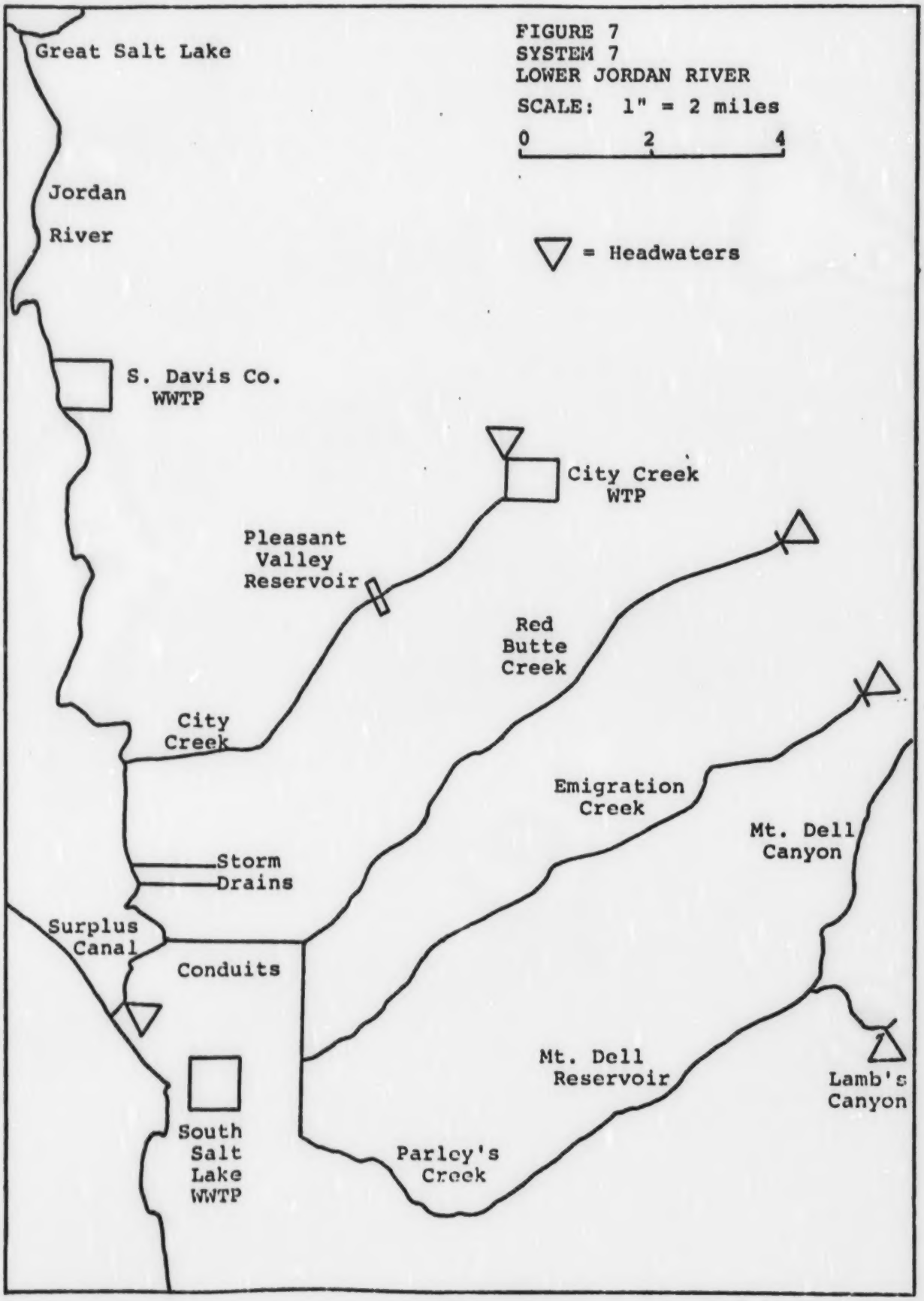


FIGURE 7
SYSTEM 7
LOWER JORDAN RIVER
SCALE: 1" = 2 miles
0 2 4
Great Salt Lake
Jordan River
= Headwaters
S. Davis Co. WWTP
City Creek WTP
Pleasant Valley Reservoir
Red Butte Creek
City Creek
Emigration Creek
Mt. Dell Canyon
Storm Drains
Surplus Canal
Conduits
Mt. Dell Reservoir
Lamb's Canyon
South Salt Lake WWTP
Parley's Creek

points within the systems. Records describing withdrawals by the irrigation diversions were sparse, however. A further weakness in the development of the flow regime was the lack of information concerning the location of incremental return flows. These flows were estimated through an analysis of U.S.G.S. records.

Velocity-discharge and depth-discharge relationships are required by QUAL for calculation of the parameter K_2 and travel time determination. These relationships can be developed from data collected at each U.S.G.S. gaging station and distributed upon the basis of slope with the following difficulties:

1) There are only a limited number of U.S.G.S. stations located on mainstream or headwater reaches and with the data available from these stations can not be truly representative of the entire system. Besides the potential statistical problem, U.S.G.S. stations are usually selected for their suitability for flow measurements and sites often do not have representative channel cross-sections.

2) Due to a lack of field data in this area it was impossible to determine with any statistical significance if the assumption that velocity-discharge and depth-discharge relationships would be similar for reaches with similar slope was correct.

The most serious data deficiency in the seven systems was

the lack of water quality data describing the conditions existing in the tributaries to the mainstream. In the lower Jordan River, where the river's flow is substantially decreased by irrigation practices, this problem is particularly acute. The quality of tributaries and return irrigation flows, although distributed, have the most significant influence on the quality character of the river. Together these flows can become major dilution or quality deterioration factors. The mainstreams, however, have been recently surveyed, allowing in most cases reasonable estimation of tributary water quality levels.

APPLICATION OF QUAL

Interpretation of simulations produced by QUAL II in the course of this study must be done with care because of the unfortunate data situation. Verification of the modified models requires a complete set of data describing both the tributary and mainstream conditions. As tributary water quality data were often not available, estimates were made from the sparse historic data base. Simulation results illustrated here and in the supporting documentation reflect as much the reliability of tributary estimates as they do model capabilities.

For purposes of illustration, the results of simulation with QUAL II on System 2, Upper Provo River, were selected. Rather

than the actual printout, simulation curves are provided to familiarize the reader with QUAL II output capabilities.

Parameters that coincided directly with historic data in the river system were DO, Hex-Valent Chromium, Boron, TDS, Nitrite, Phosphorus, Ambient Coliforms and Nitrate. The BOD profile is very similar to the observed historical measurements except that there is a constant variation of about one mg/l throughout the system. Ammonia deviates from the norm slightly in the fourth and sixth reaches. Temperature dips below the projected values in the fourth and fifth reach. (Figures 8-18)

QUAL II simulations of the remaining systems are contained in the supporting data. Simulation was good with one exception, the simulation of Utah Lake. The conclusion drawn from these attempted simulations was that QUAL II cannot give accurate results when applied to Utah Lake. Several postulates as to the routing unreliability are:

1) In QUAL-1 model assumptions, a simulated stream is well mixed both vertically and laterally, major assumptions. Both of these assumptions are violated in large, shallow Utah Lake.

2) Detention time of the lake is so great that it violates the low flow summer verification period.

3) When routing QUAL on a shallow lake of Utah Lake's

FIGURE 8
UPPER PROVO RIVER
VERIFICATION OF QUAL
FOR BOD

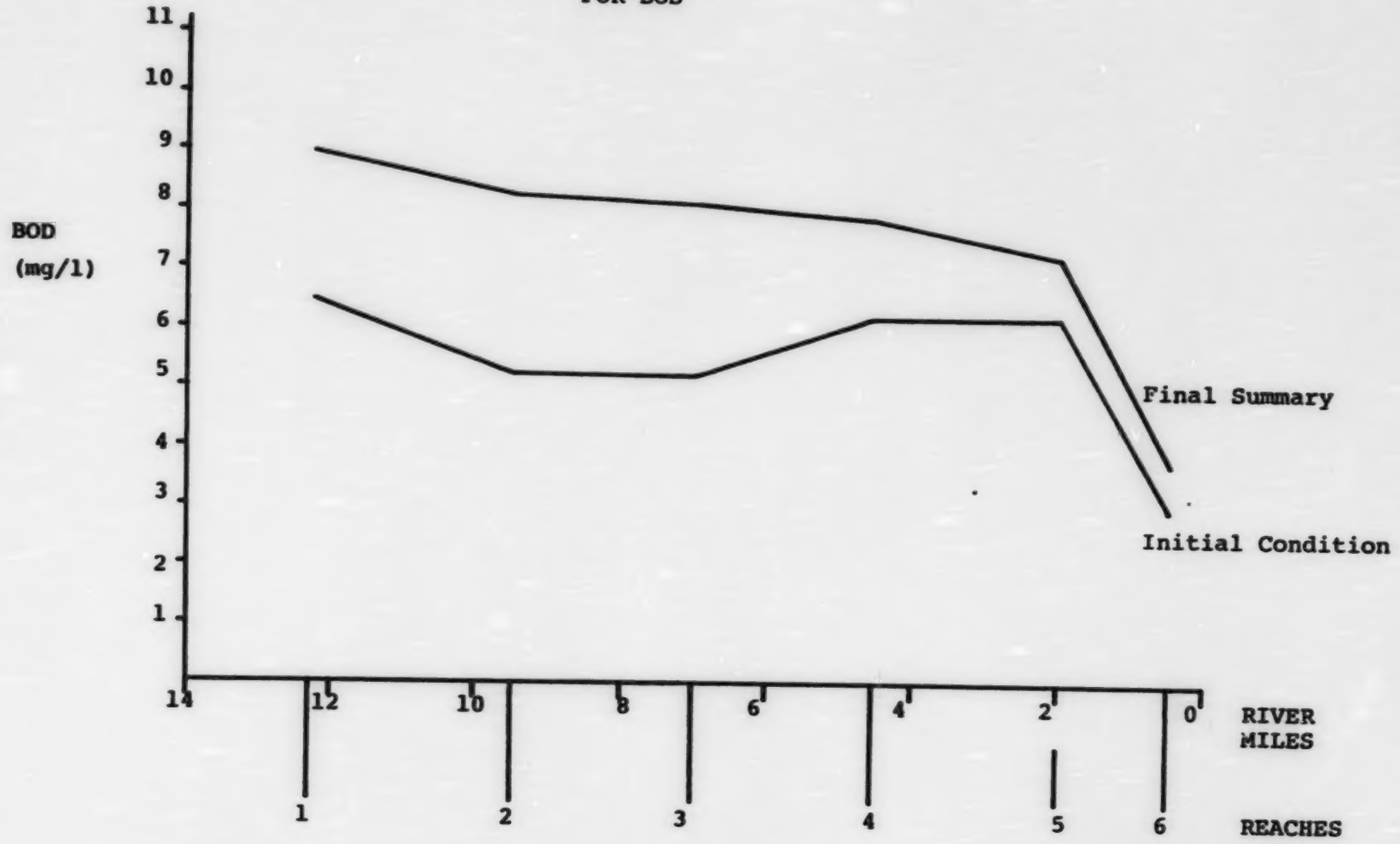


FIGURE 9
SYSTEM 2
UPPER PROVO RIVER
VERIFICATION OF QUAL
FOR DO

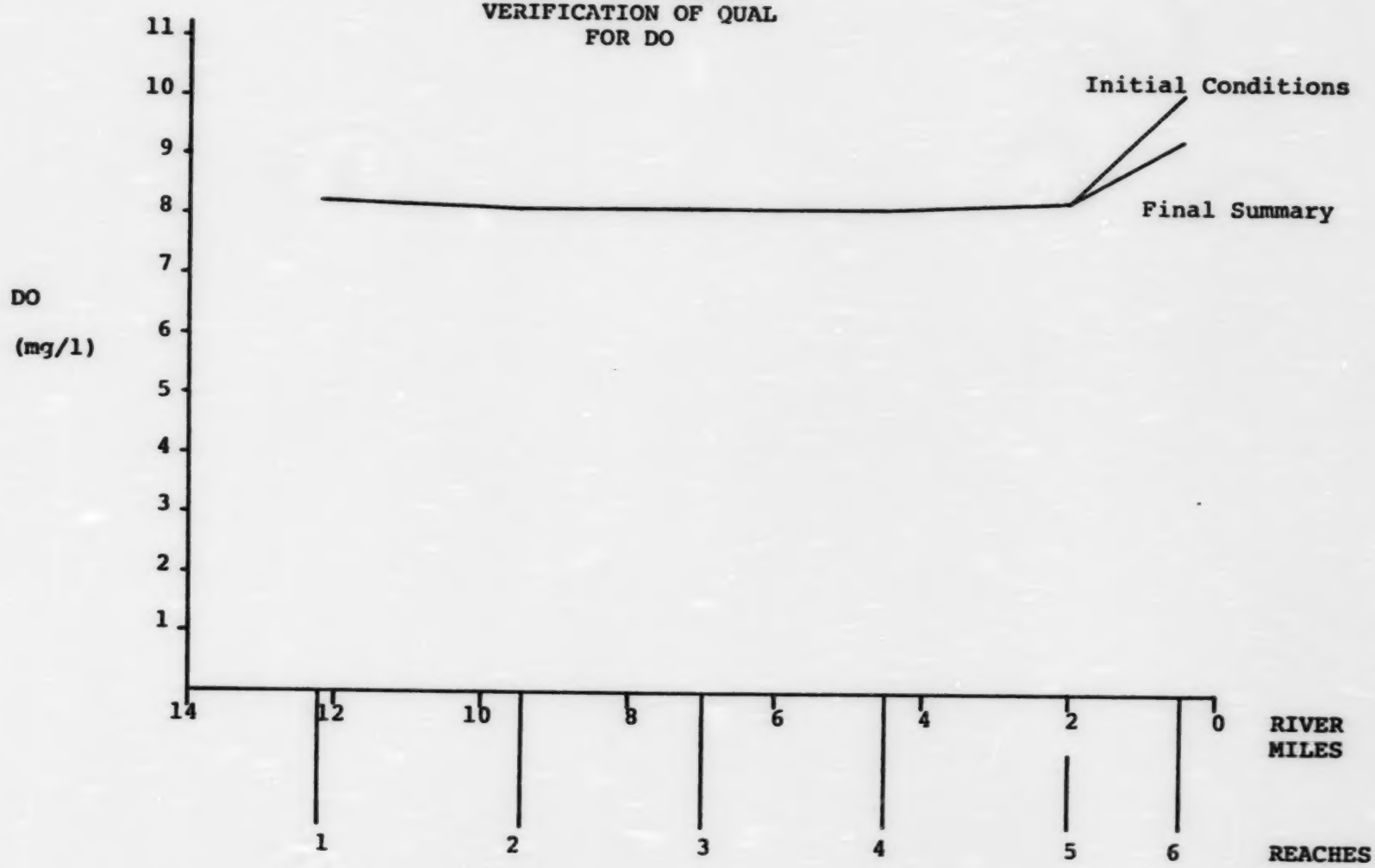


FIGURE 10
SYSTEM 2
UPPER PROVO RIVER
VERIFICATION OF QUAL
FOR AMMONIA

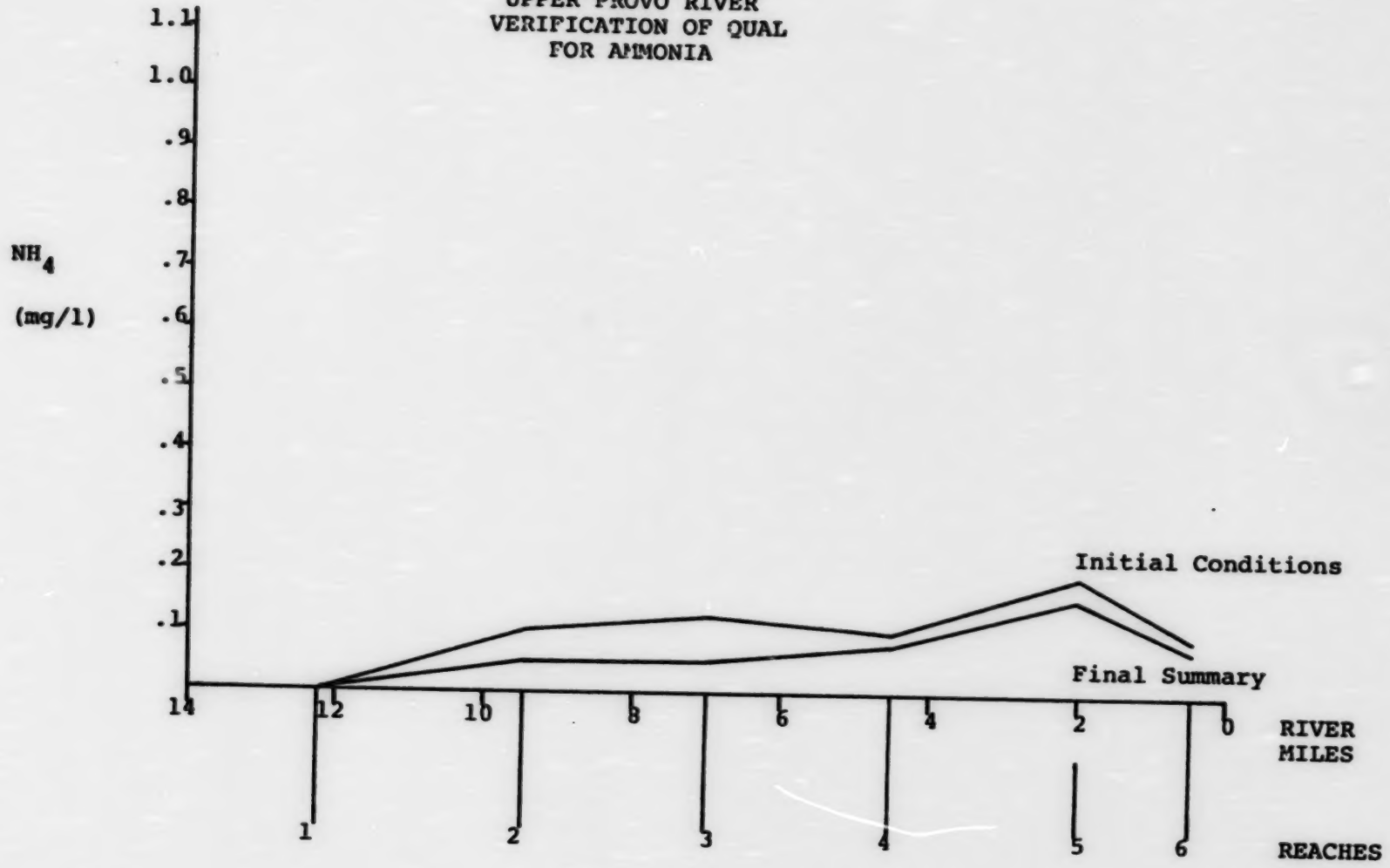


FIGURE 11
SYSTEM 2
UPPER PROVO RIVER
VERIFICATION OF QUAL
FOR NITRITE

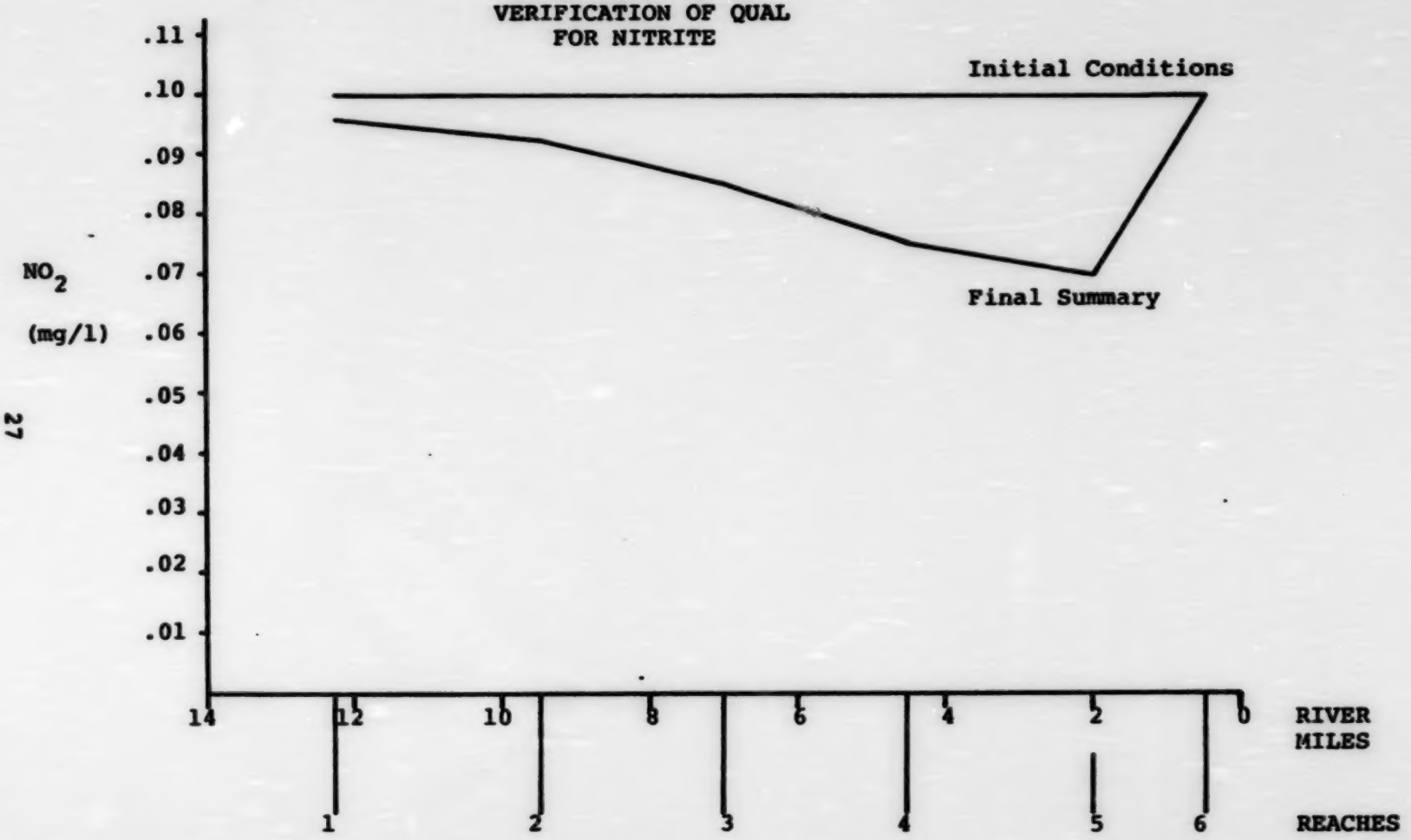


FIGURE 12
SYSTEM 2
UPPER PROVO RIVER
VERIFICATION OF QUAL
FOR NITRATE

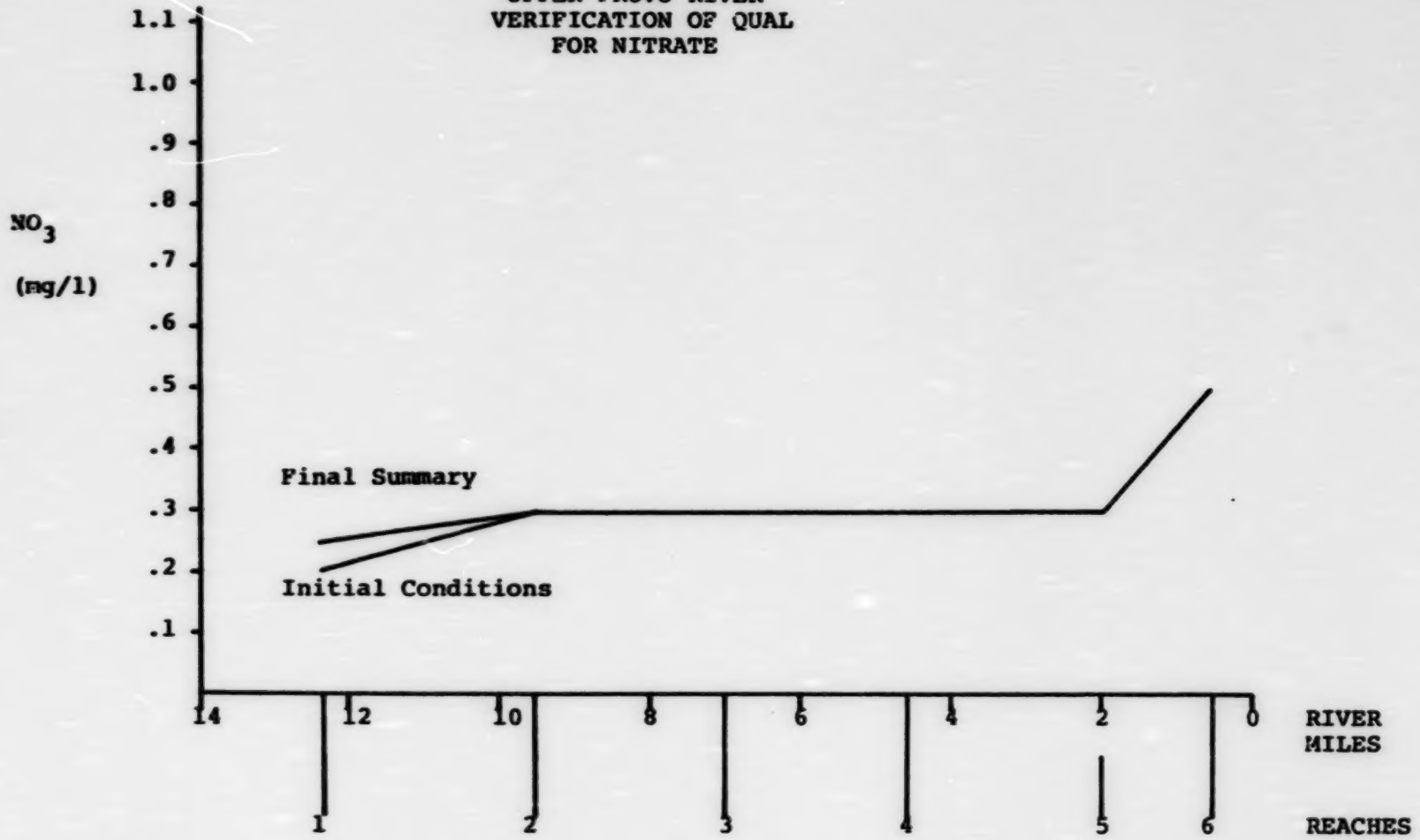


FIGURE 13
SYSTEM 2
UPPER PROVO RIVER
VERIFICATION OF QUAL
FOR PHOSPHORUS

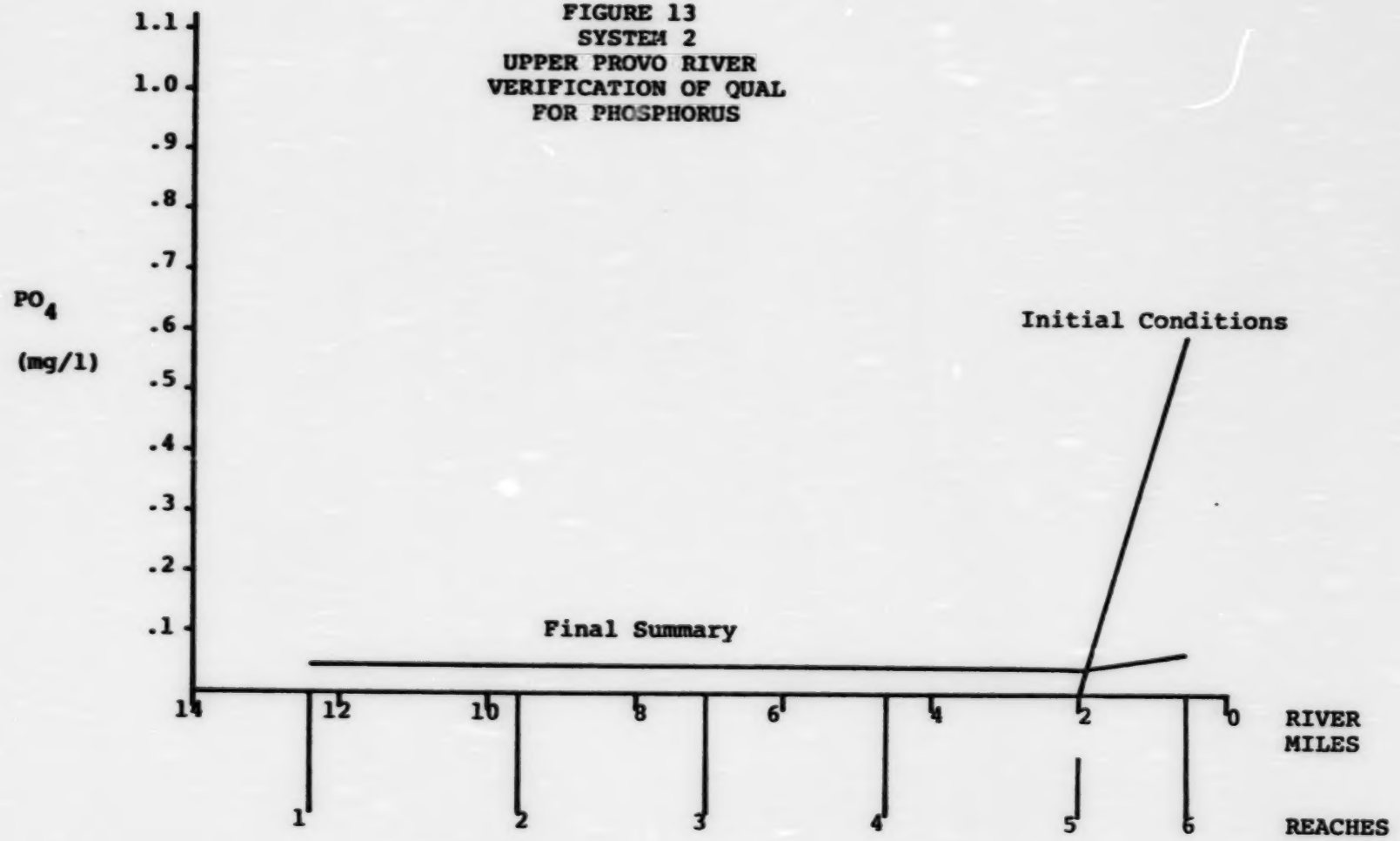


FIGURE 14
SYSTEM 2
UPPER PROVO RIVER
VERIFICATION OF QUAL
FOR TEMPERATURE

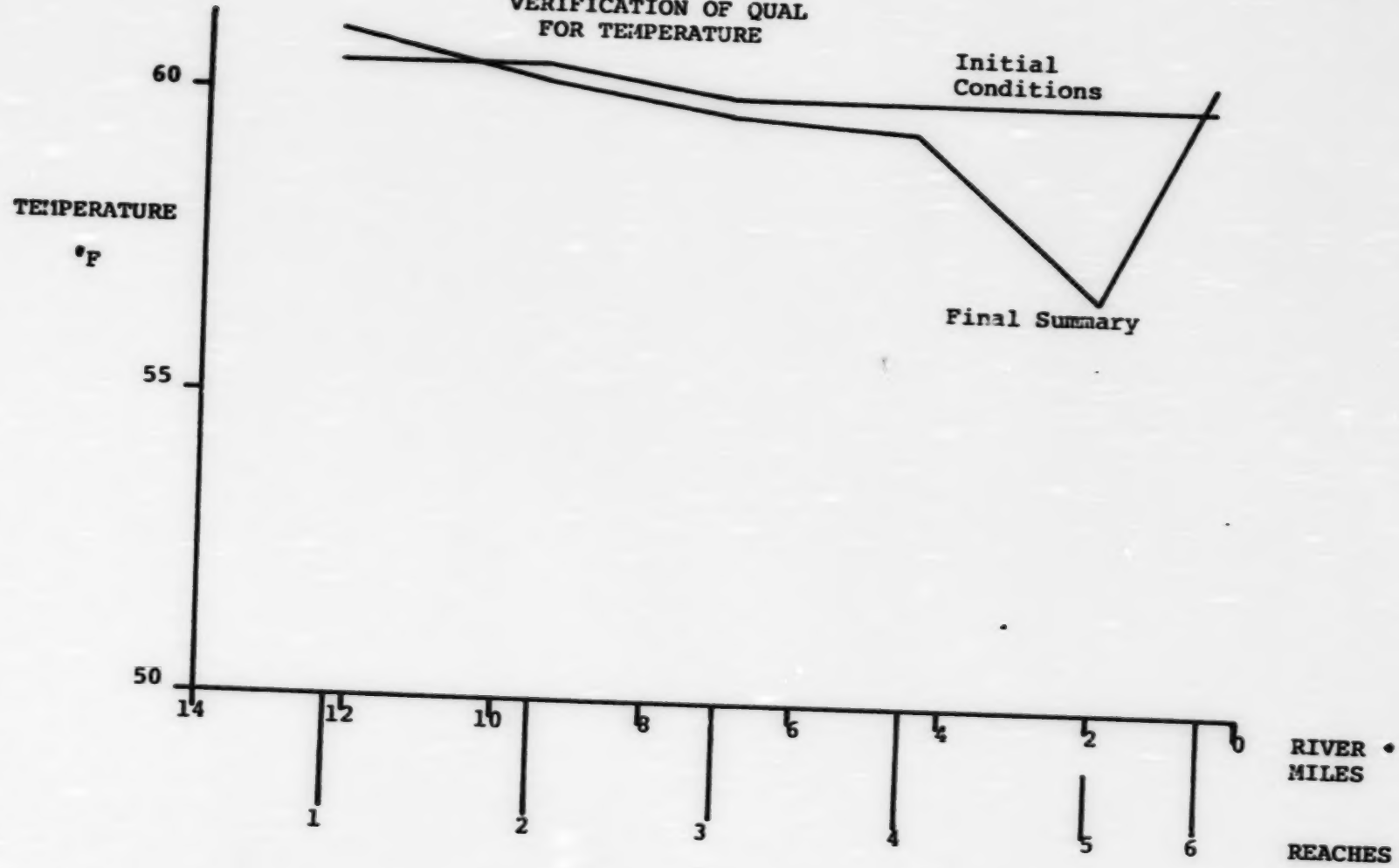


FIGURE 15
SYSTEM 2
UPPER PROVO RIVER
VERIFICATION OF QUAL
FOR COLIFORMS

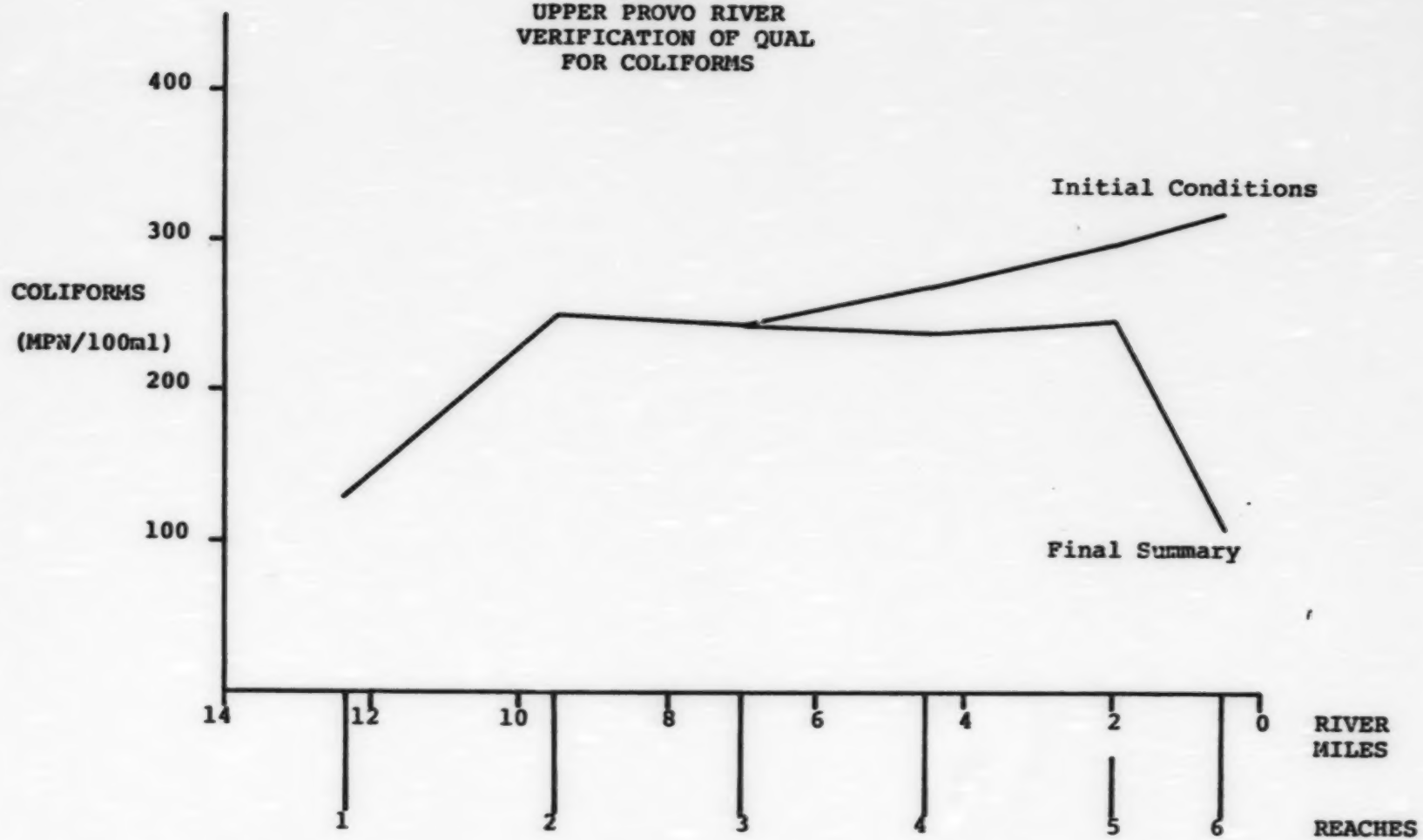


FIGURE 16
SYSTEM 2
UPPER PROVO RIVER
VERIFICATION OF QUAL
FOR CM-1

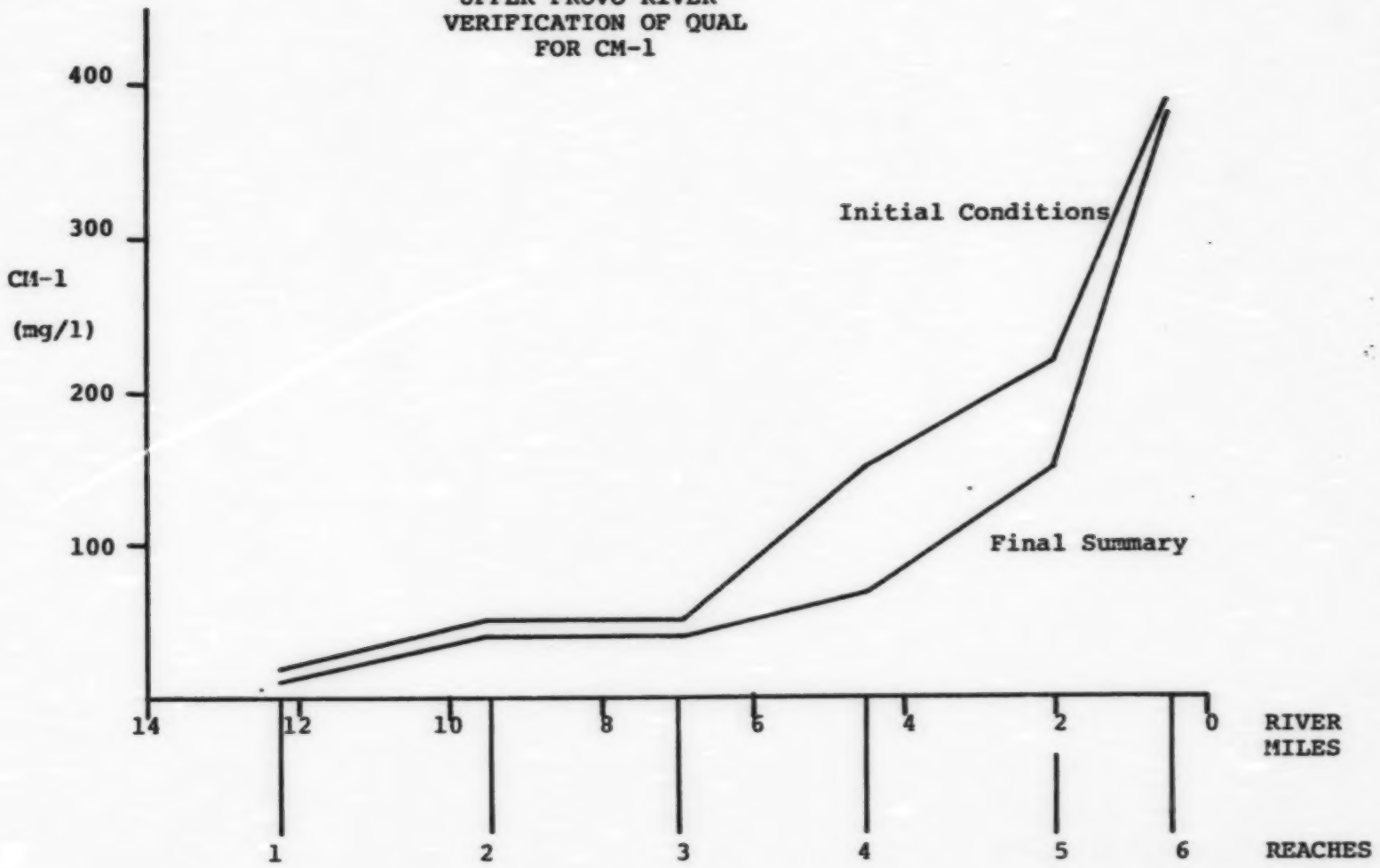


FIGURE 17
SYSTEM 2
UPPER PROVO RIVER
VERIFICATION OF QUAL
FOR CM-2

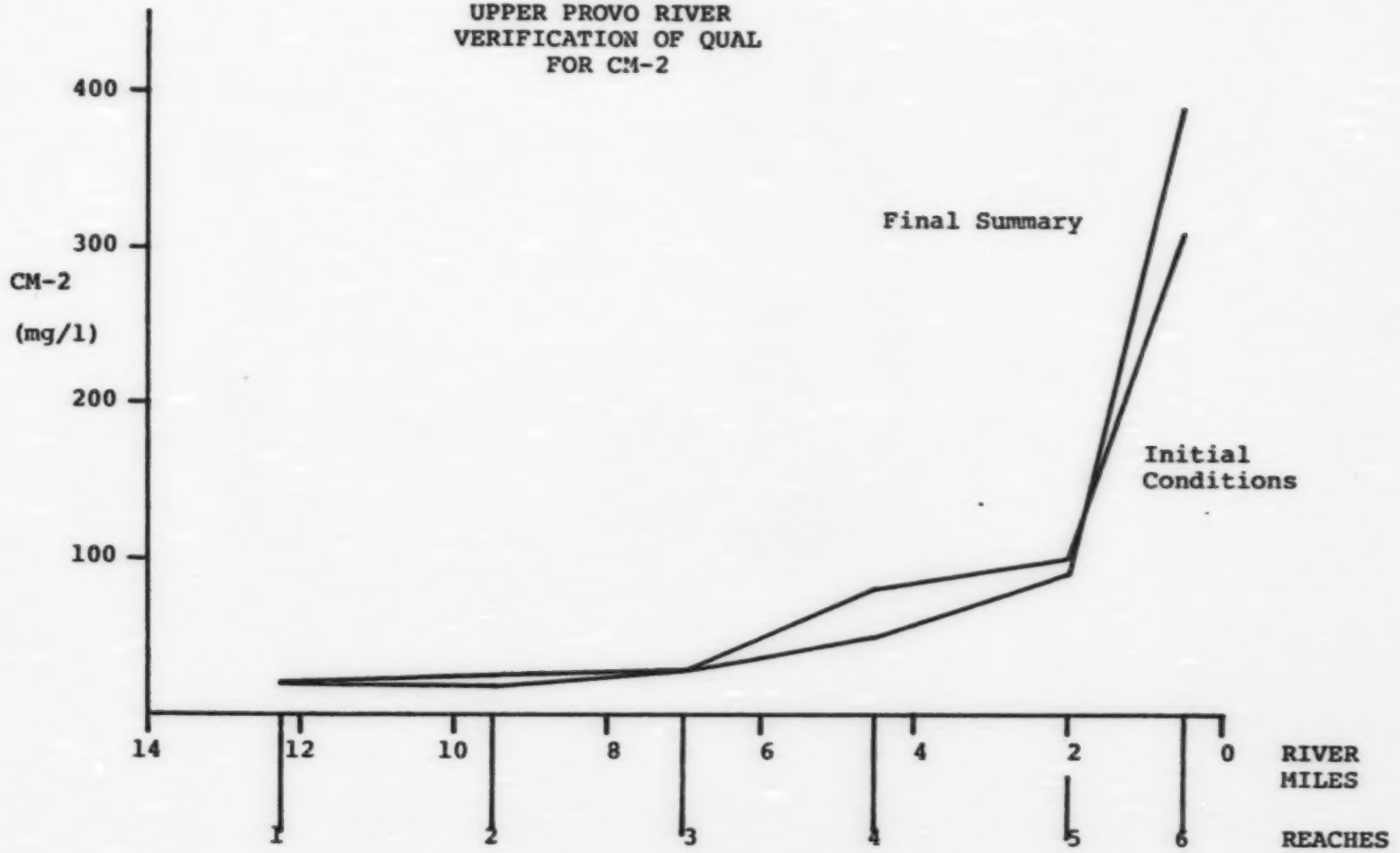
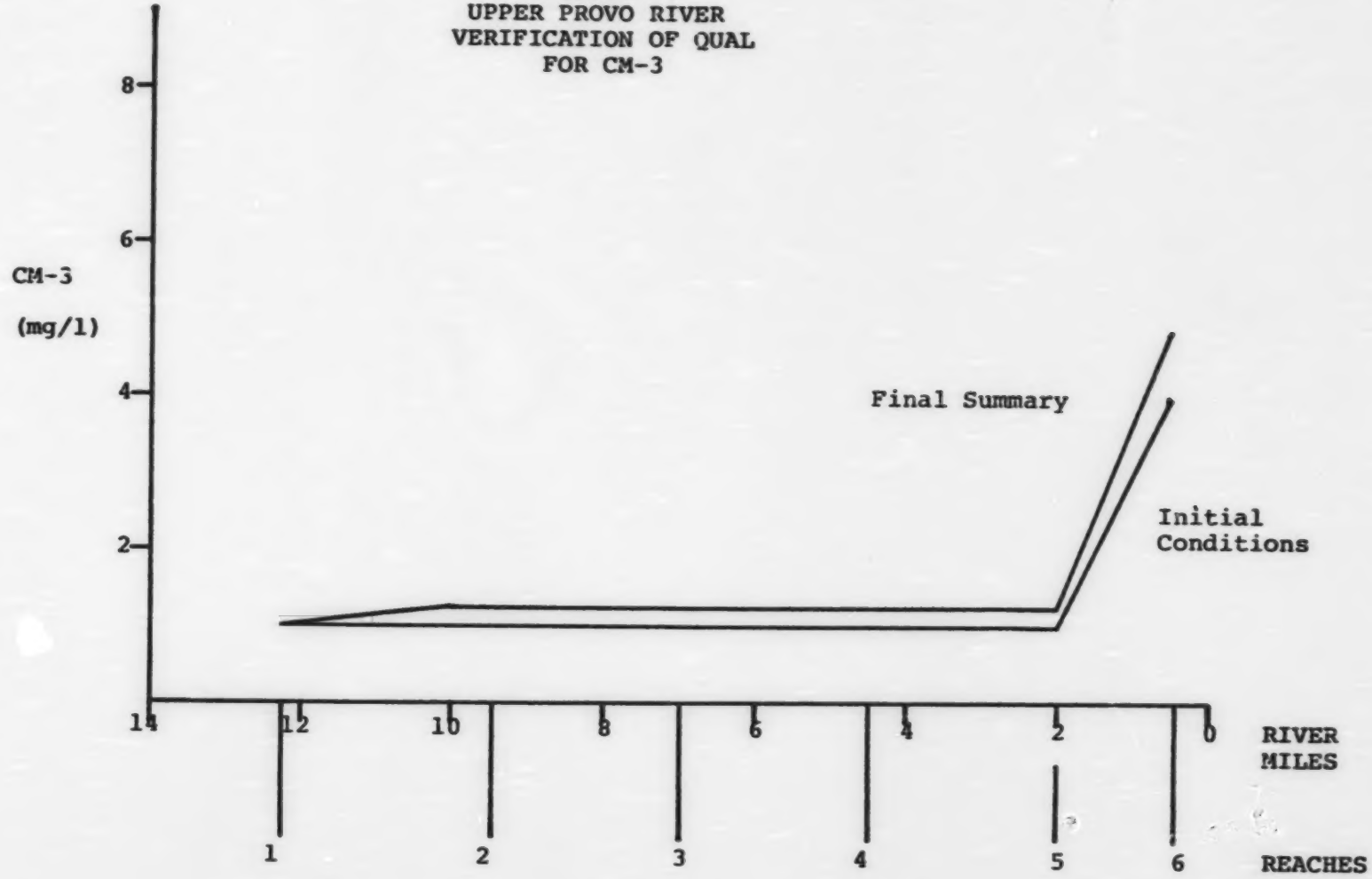


FIGURE 18
SYSTEM 2
UPPER PROVO RIVER
VERIFICATION OF QUAL
FOR CM-3



physical dimension the climatological data overly influences the climate-related parameters in the system.

4) All pertinent climatological data used for Utah Lake was monitored at the U.S.W.B. station at Salt Lake City Airport, which is 1000 feet lower in elevation and 60 miles north of the lake.

Dissolved Oxygen, Conservative Minerals, Coliforms, Ammonia, Nitrate, and Phosphate were representative of the quality of Utah Lake up to a point in the area of Geneva Steel plant, where deviations occur. The lower simulated temperature was totally out of the scope of verification for the above reasons. BOD samples of Utah Lake were taken only near stream confluences and industrial outflows. A predicted value was used as initial conditions and the simulation exceeded anticipated values.

APPLICATION OF DRM TO DEER CREEK RESERVOIR

DATA AVAILABILITY

The only pertinent data collected on Deer Creek Reservoir in recent years in terms of quality parameters has been taken by Metropolitan Water District. Weekly thermal profiles and monthly coliform samples were taken for 1972. Templeton, Linke and Alsup (TLA) have taken intermittent readings of the inflow and outflow from the reservoir.

The TLA quality samples taken did not measure all parameters and the reservoir sampling was not coordinated with the Provo River sampling. Thus the data collected was not adequate for verification of Deer Creek Reservoir.

Flow into and out of the reservoir system was measured by Provo River Commissioner and U.S.G.S. stations. This flow data was used in the DRM input of WBAL program.

All meteorological data was obtained from U.S.W.B. in Salt Lake City.

SIMULATION RESULTS

Analysis of the results of thermal simulations and water quality routing within Deer Creek Reservoir are difficult as little supporting data is available. Until such time that extensive data is collected upon this impoundment, the actual internal conditions will remain a matter of conjecture. The simulations produced by this study were based largely upon estimation. DRM II, however, performed well. Carbonaceous BOD, organic nitrogen, nitrate nitrogen, and dissolved oxygen curves from simulations of Deer Creek Reservoir were chosen for illustrations (Figures 20 through 23, respectively.)

Temperature

From the graphs of temperature versus elevation in the

printout a picture of the yearly temperature regime in the reservoir may be obtained. The reservoir starts completely mixed at 4°C on the 61st day (March 1). By the 90th day the reservoir is stratified. It continues in this manner, becoming more and more stratified, until the 180th day. By this point the reservoir is completely stratified, which is the condition one would expect in a quiet body of water such as Deer Creek Reservoir. The reservoir remains in this stratified state until the 270th day, when it begins fall turnover. On day 300, the last day simulated, the reservoir is completely mixed. The temperature profiles obtained from Metropolitan Water District accurately verified the DRM temperature profiles. The results appear to be consistent with available temperature of the lake within the bounds of the meteorological conditions. (Figure 19)

Carbonaceous BOD

Figure 20 illustrates the decay of carbonaceous BOD within the reservoir following spring turnover. The decay of carbonaceous BOD in all layers is similar until day 150. At this time the effect the the C_M (benthic BOD) becomes apparent in the hypolimnion. This same BOD appears in the shifting thermocline as a result of mixing with the hypolimnion. The lack of carbonaceous BOD is a result of two factors:

1) the inflow quality of the Provo River is negligible

FIGURE 19
TEMPERATURE vs. ELEVATION
DEER CREEK RESERVOIR

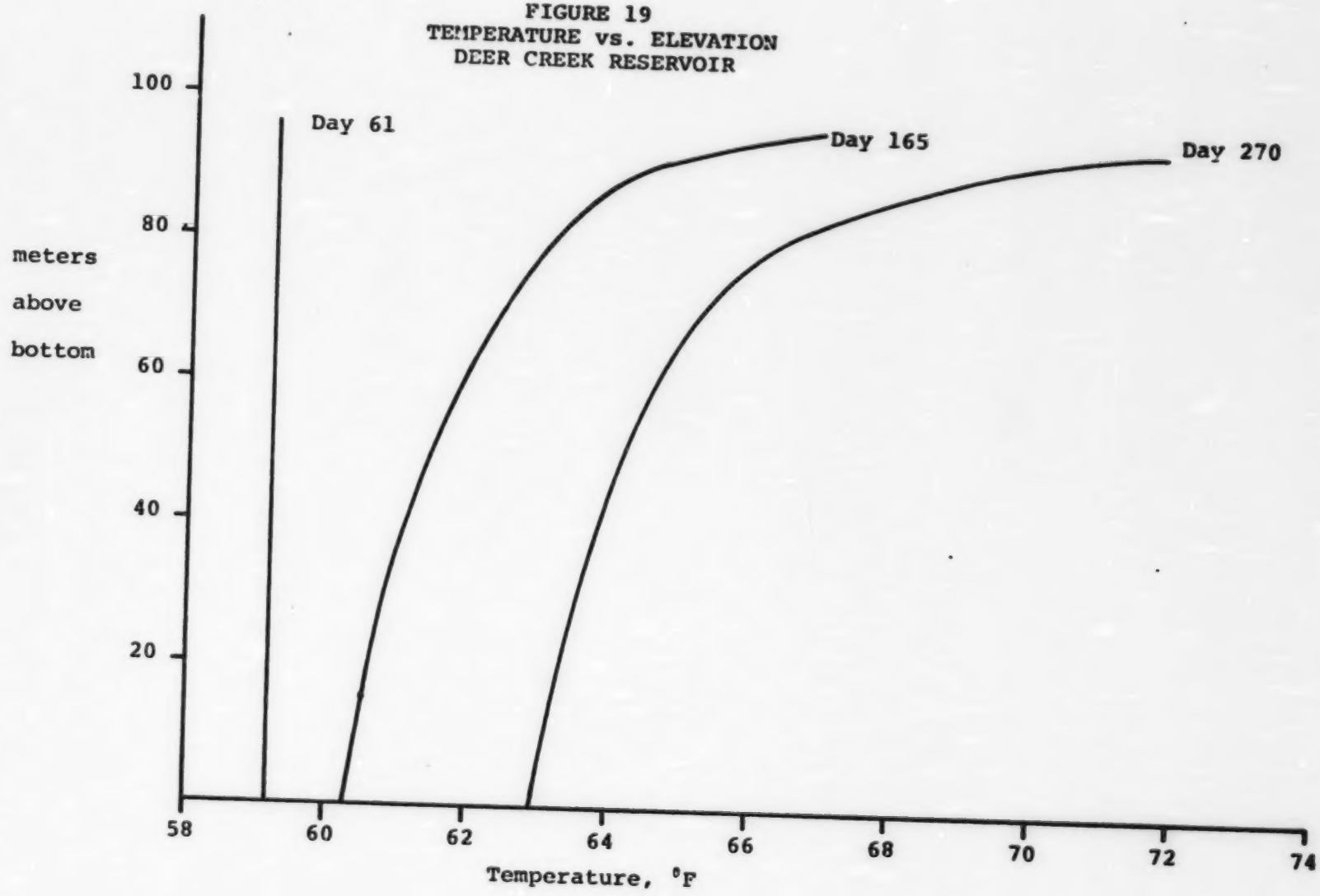
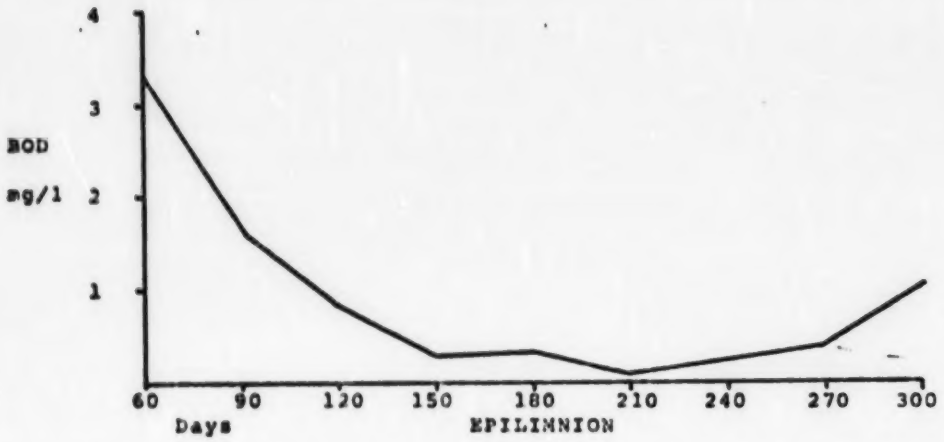
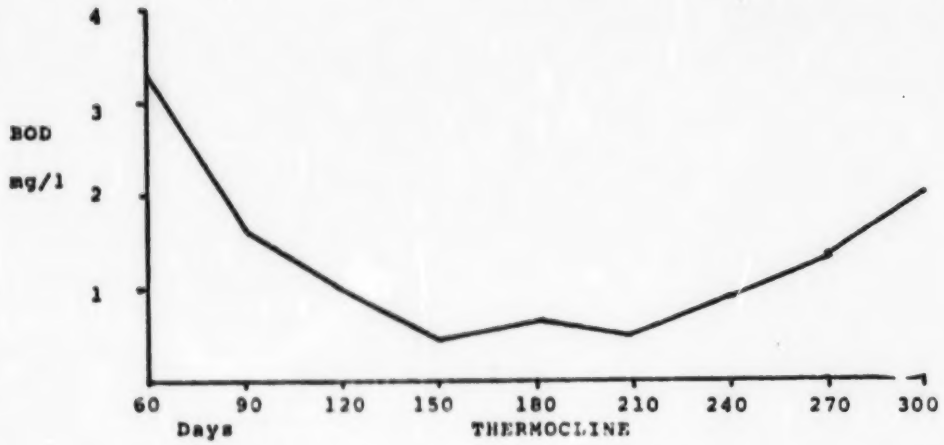
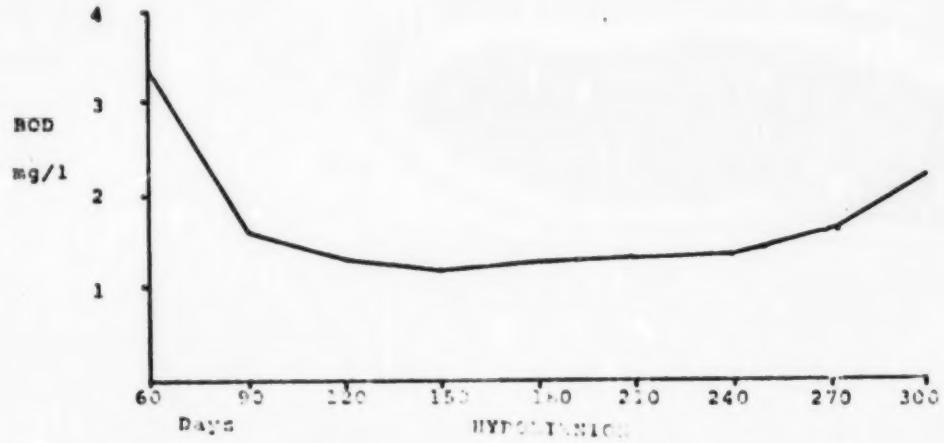


FIGURE 20
VERIFICATION OF BOD







over a short period of time when compared to the total volume of Deer Creek Reservoir

2) The low C_M (.01 mg/l-day) utilized

NITROGENOUS BOD

Before examining the results of simulation of the nitrogen forms it is necessary to mention that the Modified Deep Reservoir model assumes organic nitrogen is effectively a measure of the ambient algae population. This is compared with organic nitrogen in streams, which reflects the amount of decaying organic materials found in wastewater discharges or surface runoff. The "living" organic nitrogen in the reservoir is of a different character from the "dead" organic nitrogen of a stream, and hence decays to nitrate at a very different rate. The synthesis of available nitrogen into algal cells is the logical result of long detention times and river inflows which are insignificant over the short term when compared to the total volume of the lake.

The nitrogen cycle occurring in deep impoundments is illustrated by the results of runs on Deer Creek Reservoir. (Figures 21,22)

1) Increase in concentration in the epilimnion as a result of the synthesis of nitrate into organic nitrogen reflecting the ideal conditions for photosynthesis in this upper layer -- this increase levels off as all available

FIGURE 21
VERIFICATION OF ORGANIC NITROGEN

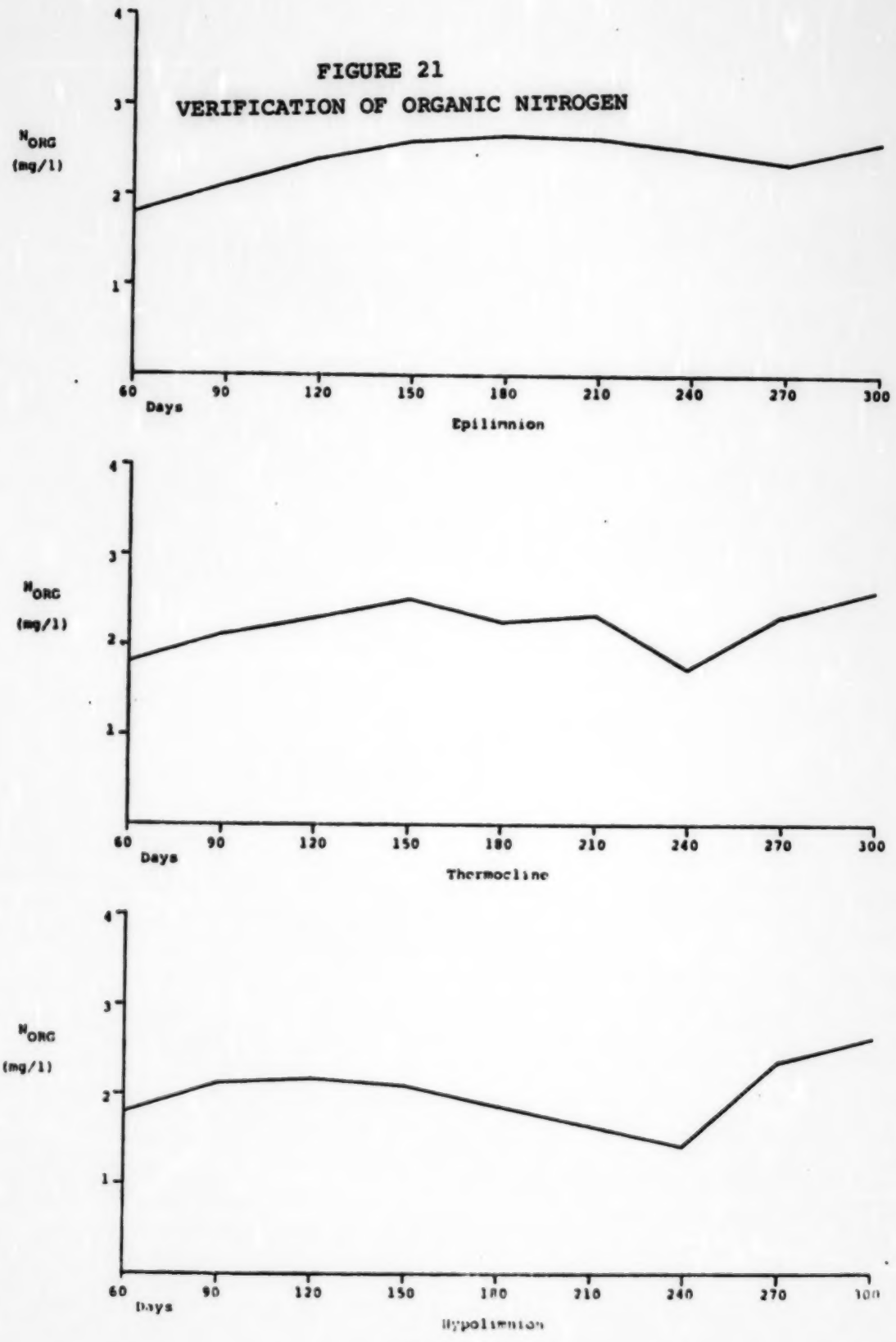
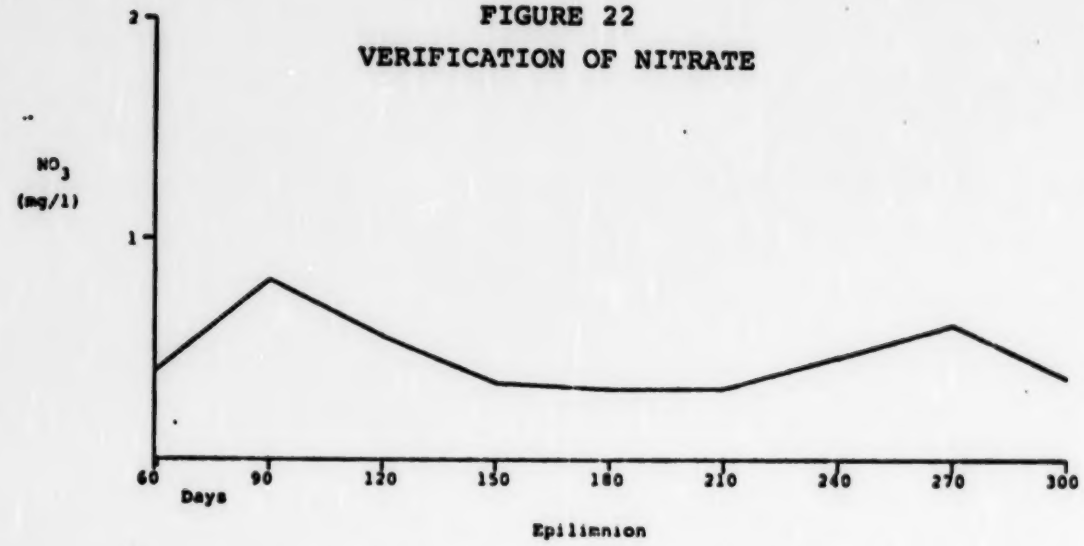
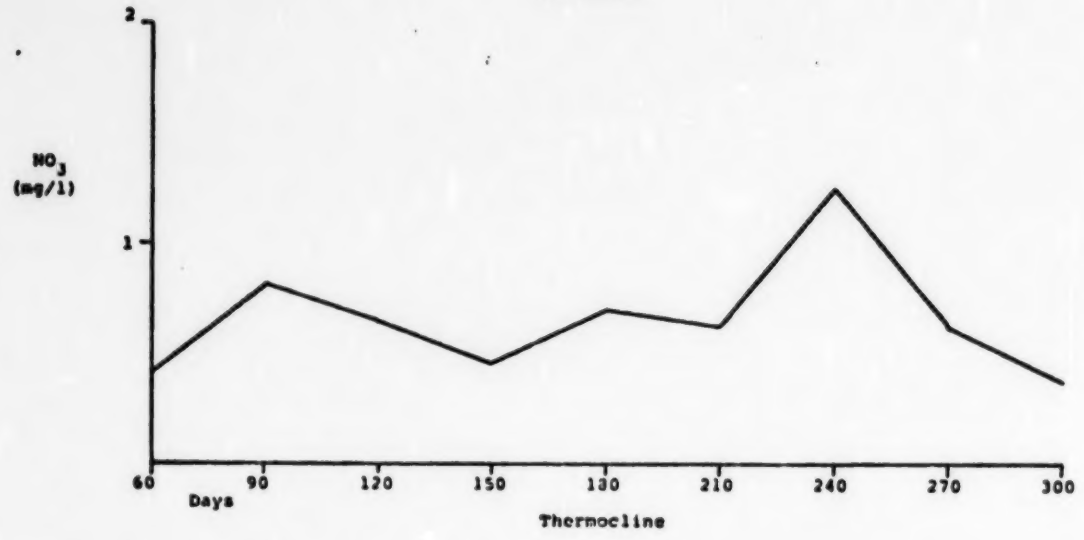


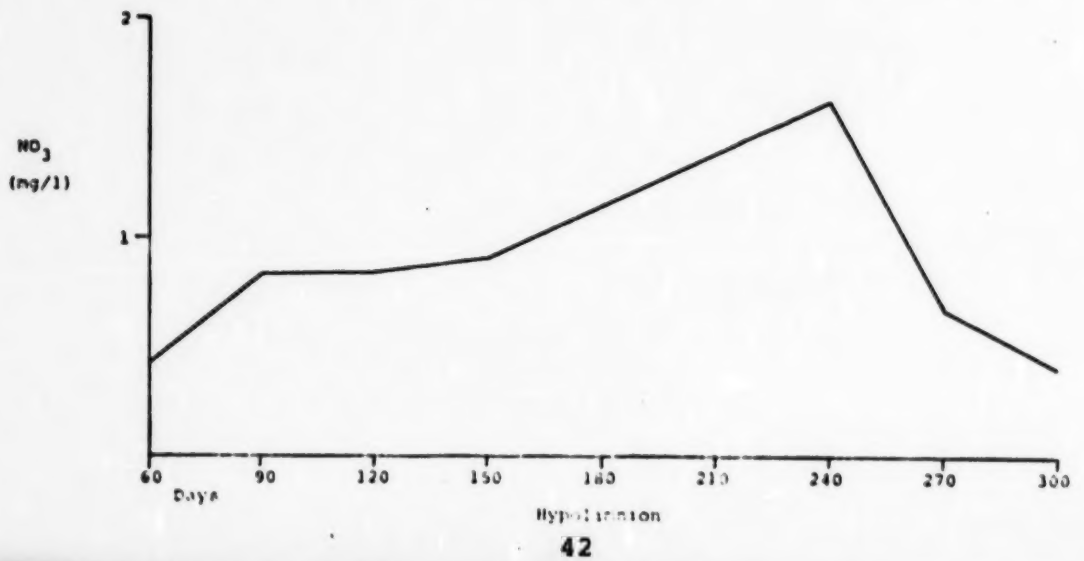
FIGURE 22
VERIFICATION OF NITRATE



Epilimnion



Thermocline



Hypolimnion

nitrate is utilized.

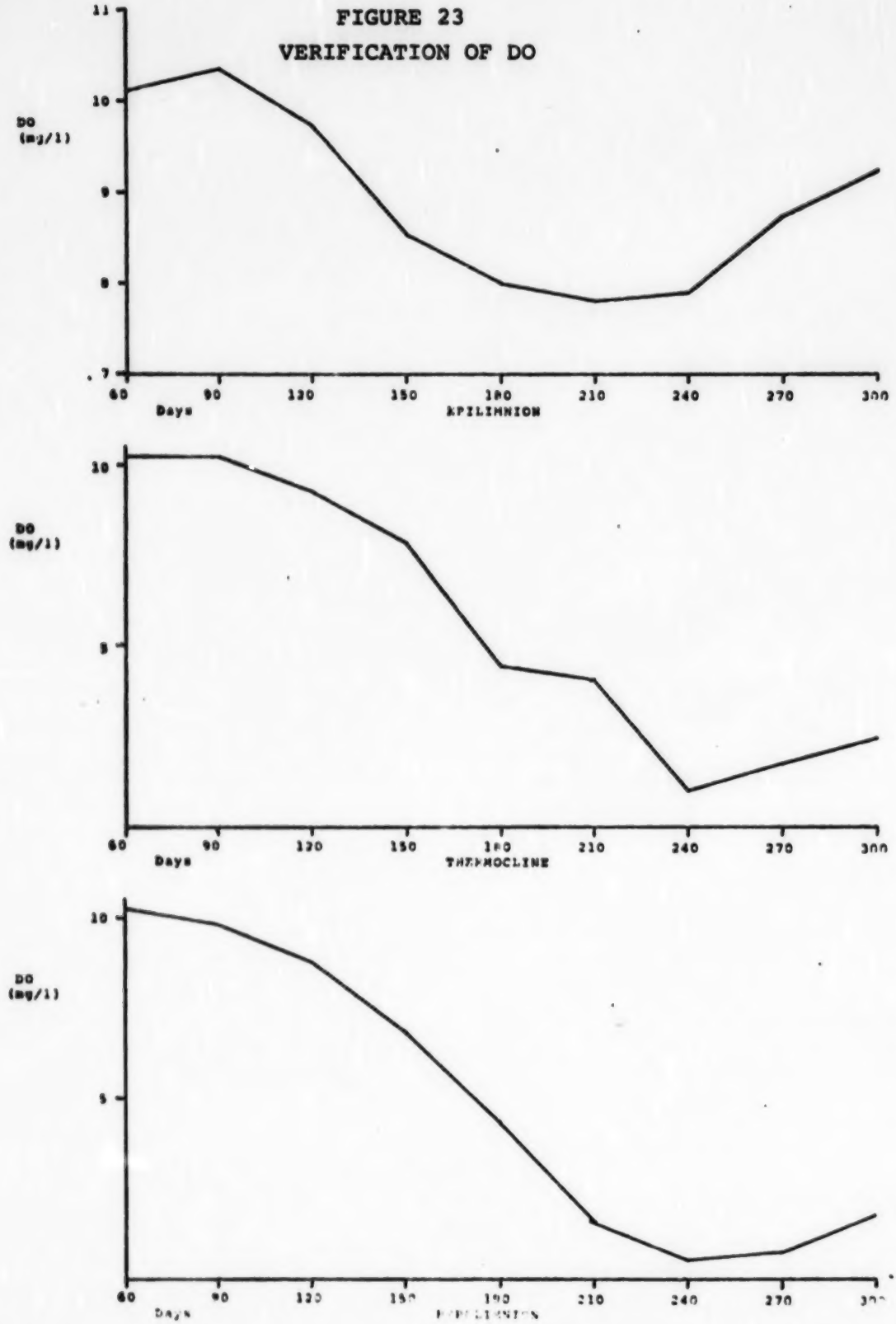
2) A decrease in the organic nitrogen concentration in the hypolimnion reflecting poor conditions for photosynthesis with no replacement of decayed organic nitrogen

3) Erratic variations within the thermocline reflecting mixing with hypolimnion and epilimnion through positional shifts -- this process literally moves nitrate up for synthesis while moving organic nitrogen down for decay. Ammonia and nitrite (not illustrated here) or nitrate nitrogen remain only in trace amounts in the thermocline and hypolimnion where the organic nitrogen concentration is low. In the epilimnion where the organic nitrogen levels are significantly higher small concentrations are maintained by its decay. As would be expected, the plots for nitrate follow a reverse pattern of the organic nitrogen plots. Excellent conditions for photosynthesis results in the low levels of nitrate in the epilimnion. Poor light conditions in the hypolimnion results in a substantial increase due to the decay of organic nitrogen. And the shifting thermocline again reflects the mixing phenomenon.

Dissolved Oxygen

The DO curves (Figure 23) reflect for the large part the carbonaceous and nitrogenous BOD curves. In the thermocline and hypolimnion the lack of reaeration and ambient BOD levels constantly reduce the DO levels. The rate of this decrease

FIGURE 23
VERIFICATION OF DO



is critical. If BOD concentrations were larger in the hypolimnion the dissolved oxygen supply could easily become depleted before the fall turnover.

The curve in the epilimnion reflects the balance between BOD and the reaeration process. As the carbonaceous BOD is depleted, reaeration replenishes the diminished oxygen supply.

CONCLUSIONS

MODEL CAPABILITIES

In QUAL, only the final steady state prediction has validity as the transitional modeling is invalid due to its inability to consider the diurnal variation in DO concentrations and in the related parameter, temperature. This discussion is applicable particularly to QUAL II because of its pretense of modeling transitional effects for short durations within the mainstream. Although QUAL II is refined in many facets, the lack of consideration of large diurnal variations in DO levels found in rivers such as the Jordan River invalidates any transitional analysis. QUAL II presently has a versatile framework which will readily accept modifications to allow for diurnal variability of constituents and more reliable transitional modeling.

Use of Deep Reservoir Model II is inhibited by the lack of

sufficient documentation concerning the original model. Water quality modifications, although made upon a reliable theoretical base, require extensive field data for verification. The model has exhibited good potential for becoming a reliable planning tool.

RECOMMENDATIONS

There are two categories into which recommendations fall. The first is concerned with the correlation that must be maintained between theoretical development and actual field data. As the scope of this study limited the correlation to historic data, many specific needs of these models could not be fulfilled. The data that was collected previously was collected for numerous purposes other than modeling, and could not be expected to fill the needs of a refined water quality model. In some cases, the data was weak. In other cases it simply did not exist.

The primary recommendation of this project would be to collect specific data to fulfill the needs of these programs. The specific critical areas of need are listed below:

1) Definition of the water quality levels existing within tributaries to the mainstreams of the seven QUAL systems

2) Definition of typical velocity-discharge and depth-discharge relationships for the mainstreams of all systems

3) Definition of the ranges of contribution from the benthos of BOD (k_m) in all systems

4) Definition of the extent and timing of thermocline development in Deer Creek Reservoir

5) Definition of the seasonal variation with depth of water quality distribution within Deer Creek Reservoir

6) Definition of the flow patterns existing in the Jordan River, Provo River and Spanish Fork River with emphasis on diversions and return flows

7) Definition of the constituent levels found in certain domestic discharges

The second area of recommendation is concerned with further development of the models as a result of theoretical weaknesses observed within the models. Both QUAL II and Deep Reservoir Model II require further refinement before reaching their intended levels of reliability. With Deep Reservoir Model II the modifications are presently unknown, but can be expected as simulation results are compared with field data. One area where a need is suspected is in the area of BOD routing. Here the present relationships are lacking, but no information is now available to indicate where the correction should be made.

QUAL II, on the other hand, has specific theoretical weaknesses. These include the application of first order kinetics to transitional nitrogen routing and the lack of consideration of diurnal variation of dissolved oxygen and related parameters. Recommendations in this area are therefore:

8) Further refinement and development of Deep Reservoir Model II, including correlation with field data

9) Modification of QUAL II to accommodate diurnal variations of dissolved oxygen, water temperature, BOD, and oxygen production by algae

A final recommendation which both of the above categories is concerned with regards the potential planning uses of the river models. Simulations with QUAL II have indicated that tributary conditions, particularly incremental flows, are a major factor in defining the water quality character of these river systems. Since it is known that runoff quality differs greatly in areas of agricultural and urban land use, for instance, it has become apparent in the course of this study that the runoff quality may vary significantly in the future. Stream simulations that investigate only the effects of increased domestic wastewater discharge could easily be invalid as the effect of the runoff may be large.

It is recommended that:

10) A comprehensive study be conducted to define changes of constituent levels in runoff that can be expected with changing land use